CHAPTER 600 DESIGN OF THE PAVEMENT STRUCTURAL SECTION

Topic 601 - General Considerations in Design of the Pavement Structural Section

Index 601.1 - Introduction

Design of the pavement structural section is the determination of a combination of pavement, base, and subbase layers that is best suited to specific project conditions. In California, this combination of materials placed in layers above the top of the basement soil (the grading plane) is most often referred to as the "structural section". The AASHTO "Guide for Design of Pavement Structures" refers to it as the "pavement structure".

Design of the structural section is not an exact science. The many variables involved make it impossible to reduce the problem to exact mathematical formulas based entirely on theory. The design guidelines and standards included herein are based on a wide range of information including: theory; test track studies; experimental sections; research on materials, methods, and equipment; and perhaps one of the most important of all, the observation of structural section performance throughout the state and the nation. The final structural section design must be based on a thorough investigation of specific project conditions including materials, environmental conditions, projected traffic, life-cycle economics, and on the performance of other like project structural sections under similar conditions in the same area.

Research and experimentation are continuing in order to provide improved design methods and standards which take advantage of state-of-the-art materials and methods technology. Submittal of new ideas by headquarters and district staff, especially those involved in the design, construction, maintenance, and materials engineering of the structural section is encouraged. Suggested research should be sent to the Office of Research, New Technology and Research Program in Sacramento. Suggestions for the incorporation of experimental construction features in specific projects (during the design stage) must be submitted to the Office of Project Planning and Design (OPPD) for approval before completing the final design phase of a project.

Suggestions for research studies and changes in design standards may also be submitted to OPPD for consideration, evaluation, and recommendations by the Pavement Design and Rehabilitation Committee (PDRC) which is chaired by the Structural Section and Design Standards Specialist in OPPD. The PDRC is a multifunctional committee that includes representatives from various Corporate Headquarters functional units and the Engineering Service Center (ESC), which in turn, receive input from their counterpart functional units in the Districts. The mission of the PDRC is to provide advice and recommendations on State highway system pavement structural section design issues to Caltrans Corporate Headquarters Management to ensure continued quality of pavement structural section design, construction, maintenance and rehabilitation and coordinate their decisions throughout Corporate Headquarters, the Districts and the ESC.

The Structural Section and Design Standards Specialist is also a member of the Research Program Advisors Council and, as such, has direct input on all research suggestions submitted to the Office of Research for consideration by the Research and Development Committee.

The new edition of the Caltrans "Asphalt Concrete Overlay Design Manual", will be titled the "Pavement Rehabilitation Manual". This manual, which is presently being prepared by the Office of Materials Engineering and Testing Services (METS), covers the prescribed Caltrans design of AC overlays for rehabilitation of existing asphalt concrete pavement (ACP) (utilizing a field deflection method that measures deflection of the pavement surface under a concentrated wheel load) and portland cement concrete pavement (PCCP). PCC pavement and AC pavement rehabilitation strategies are also discussed in this manual in Indexes 611.8 and 611.9 respectively.

The design of both new AC structural sections and AC overlays using the deflection method are also covered in the local agency manual entitled "Flexible Pavement-Structural Section Design

Guide for California Cities and Counties", which was developed by METS. This Manual is being updated by METS and will include design standards for PCC pavement that are essentially the same as those shown in Topics 606 and 607 of this manual.

The AASHTO "Guide for Design of Pavement Structures", although not adopted by Caltrans, is a comprehensive reference guide that provides background that is helpful to those involved in design of pavement structural sections. This reference is on file in OPPD and a copy should be available in each District. Design procedures included in the AASHTO Guide are used by FHWA to check the adequacy of the specific structural sections adopted for Caltrans projects, as well as the procedures and standards included in Chapter 600 of this manual. The AASHTO Guide was developed by a team of nationally recognized pavement design experts with detailed input from several states, including California.

601.2 Structural Section Design Objectives

Structural sections, except for experimental construction for research, are to be designed using methods or standards described herein. This will assure adequate strength and durability to carry the predicted traffic loads for the design life of each project. Alternative designs (flexible and rigid) must be considered for each project, as appropriate, per specific project conditions.

Generally, the most economical design should be selected based on the "life-cycle costs" which include initial cost, maintenance cost, and anticipated rehabilitation costs during the selected life-cycle period. The design choice may, however, be dictated by specific project conditions such as predicted uneven foundation settlements, highly expansive basement soils, groundwater, availability of materials, type of pavement on existing adjacent lanes or facilities, traffic considerations, stage construction, size of project, or other factors. Since some of these conditions can be compensated for at increased cost, they become a factor in the life-cycle cost analysis. Topic 609 discusses the pavement type selection and economic analysis procedures in detail.

601.3 Basic Structural Elements of the Roadway

The various basic structural elements of the roadway are shown diagrammatically in Figure 601.3. The characteristics and dimensions of the various types of pavements, surface treatments, bases, and subbases normally used are discussed and shown in subsequent texts and figures respectively. Standard structural section drainage systems are diagrammed herein (Topic 606) and are detailed in the Standard Plans. Specific materials requirements are described in the Standard Specifications and Standard Special Provisions (SSPs).

Topic 602 - Structural Section Design Procedures

602.1 Information to be Submitted to the Office of Project Planning and Design

The following are instructions for submittal of pavement structural section design information:

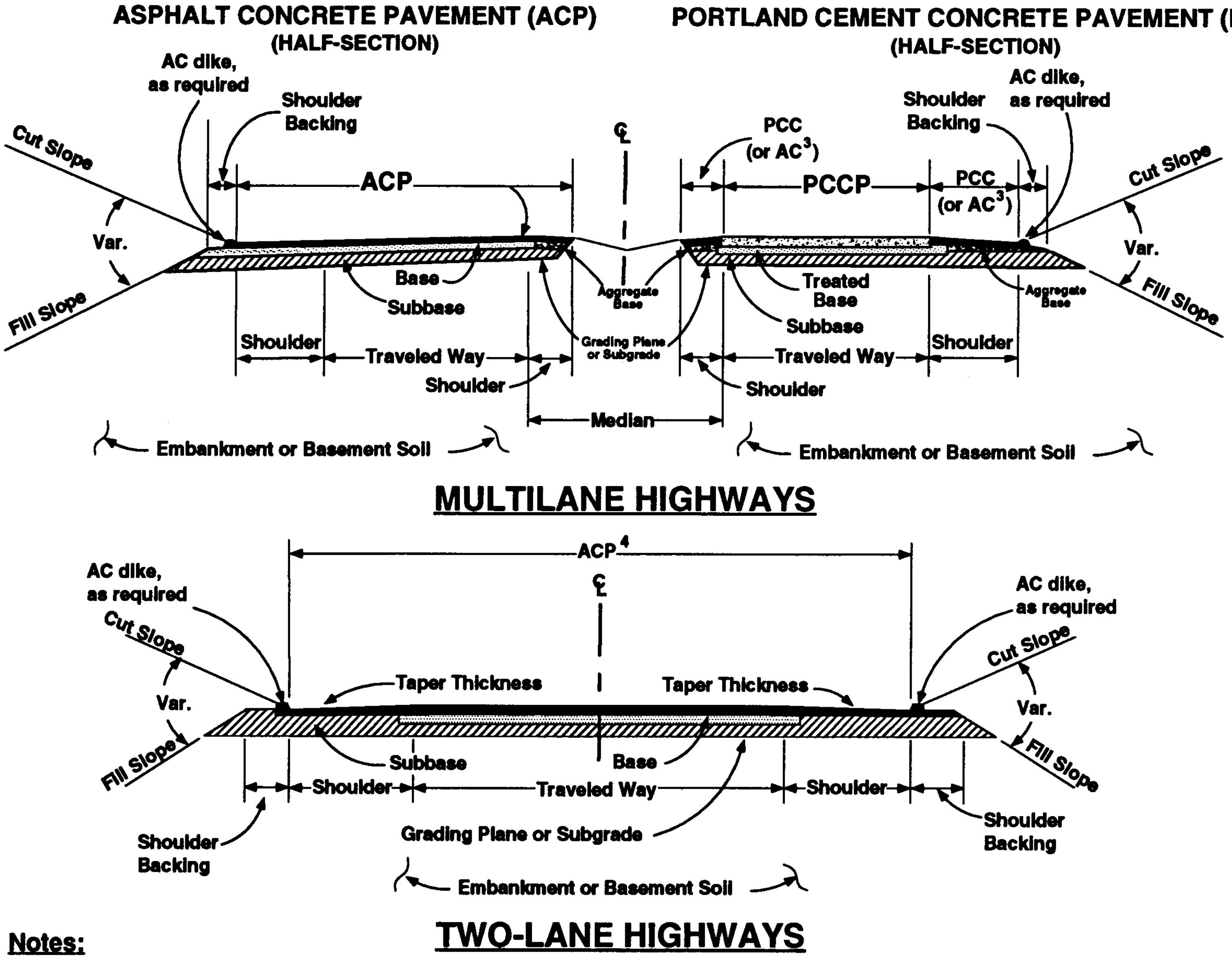
(1) *Geotechnical Design Report or Materials Report.* One copy of the Geotechnical Design Report or Materials Report for all projects must be sent to OPPD and to METS by route slip prior to the submittal of the structural section designs.

(2) *District Approvals.* One print of structural section designs that have been approved by the District Director must be sent to OPPD with a letter of transmittal and a location strip map. The letter must state the design period, R-value(s) of the basement soil, the R-value(s) selected for the structural section(s) design and the lane traffic index (TI) for each design. All attachments larger than letter size should be folded to 216 mm x 280 mm. A copy should also be sent to METS for their files.

(3) *Nonstandard or "Special" Designs.* Nonstandard designs or "special" designs to satisfy unique project specific conditions or for research purposes must be fully justified and submitted to OPPD for approval. The submittals must be in duplicate and include the proposed structural section design(s) and a location strip map. The letter of transmittal should include the design period, the

Figure 601.3

Basic Structural Elements of the Roadway



Notes:

1. These illustrations are only to show nomenclature and are not to be used for geometric cross section details, see Chapter 300.
2. Structural section drainage elements which are mandatory for most projects, both on multilane and two lane highways, are illustrated and discussed under Topics 606 and 607.
3. PCC shoulders are to be used for all PCCP new construction, however, AC shoulders may be used when justified and approved per Index 602.1(3).
4. ACP is typical, however, PCCP may be used.

R-value(s) of the basement soil(s), the R-value(s) selected for the structural section(s) design, the lane TI for each structural section, and justification for the non-standard or special design(s). A copy must also be sent to METS for their review and comments to OPPD.

(4) *Selection of Pavement Type*. A life-cycle costs analysis must be done for pavement type selection on new construction projects with TI ≥ 10.

One complete copy of the documentation for the type of pavement approved by the District Director must be submitted to OPPD, to be filed for reference. The submittal must contain the same information required in Index 602.1(2), District Approvals, for both flexible and rigid structural section designs. In addition, it must include the data required by the instructions set forth under Topic 609 for selection of pavement type.

(5) *Subsequent Revisions*. Any subsequent changes in structural sections must be transmitted in accordance with the appropriate instructions stated above with proper reference to the original.

(6) *Proprietary Items*. The use of new materials, methods, or products may involve specifying a patented or brand name method, material, or product. The use of proprietary items is discouraged in the interest of promoting competitive bidding.

The use of proprietary items requires approval by the Federal Highway Administration (FHWA) Division Office if Federal-aid funds are involved in the project. Use of proprietary materials can be approved for Caltrans by the Chief, Division of Structures for those facilities designed by the Division of Structures. Use in District designed facilities can be approved by the District Director or the District Division of Design Chief if such approval authority has been specifically delegated by the District Director. Copies of all correspondence documenting consideration and approvals of the use of proprietary items must be forwarded to OPPD to monitor conformance to this policy.

Caltrans' policy and guidelines on the use of proprietary items are covered in the Office Engineer's Plans, Specifications and Estimate (PS&E) Guide under "Trade Names." This policy is based on Public Contract Code, Division 2, Chapter 3, Article 5, Paragraph 3400. It is also virtually coincident with FHWA policy requirements. Basically the use of proprietary materials, methods, or products will not be approved unless:

(a) There is no other known material of equal or better quality that will perform the same function, or

(b) There are overwhelming reasons for using the material or product in the public's interest, which may or may not include savings, or

(c) It is essential for synchronization with existing highway or adjoining facilities, or

(d) Such use is on an experimental basis, with a clearly written plan for "follow-up and evaluation."

In addition to the PS&E Guide requirements, the FHWA requires that the following information be documented when a proprietary item is specified in the design of a pavement structural section:

(a) If it must be constructed on or immediately adjacent to an existing facility: year the existing facility was constructed and the original structural section details,

(b) Traffic Data (ADT, Peak Hour Flow, Truck Traffic AADT, TI),

(c) Accident Data,

(d) Construction cost of the project,

(e) Name of FHWA representative who reviewed the proposed project, and

(f) Tentative advertising schedule.

The review and approval process is also included in the PS&E Guide.

If the proprietary item is to be used experimentally and there is Federal participation, the request for FHWA approval must be submitted to the Chief, Value Analysis and Resource Conservation

Branch in OPPD. The request must include a work plan which indicates specific functional managers and units which have been assigned responsibility for objective follow-up, evaluation, and documentation of the effectiveness of the proprietary item. See Section 2-04 Scope of Work (“Construction-evaluated Research”) of the Construction Manual for further details on the work plan and the approval procedure.

Technical assistance is available from METS and OPPD to assist with designs that utilize new materials, methods, and products.

Topic 603 - Traffic Data for Structural Section Design

603.1 Introduction

The primary goal of the design of the pavement structural section is to provide a structurally stable and durable pavement and base system which, with a minimum of maintenance, will carry the projected traffic loading for the designated design period. This topic discusses the factors to be considered and procedures to be followed in developing a projection of truck traffic for design of the "pavement structure" or the structural section for specific projects.

Pavement structural sections are designed to carry the projected truck traffic considering the expanded truck traffic volume, mix, and the axle loads converted to 80 kN equivalent single axle loads (ESAL's) expected to occur during the design period. The effects on pavement life of passenger cars, pickups, and two-axle trucks are considered to be negligible.

Traffic information that is required for structural section design includes axle loads, axle configurations, and number of applications. The results of the AASHO Road Test (performed in the early 1960's in Illinois) have shown that the damaging effect of the passage of an axle load can be represented by a number of 80 kN ESAL's. For example, one application of a 53 kN single axle load was found to cause damage equal to an application of approximately 0.23 of an 80 kN single axle load, and four applications of a 53 kN single axle were found to cause the same damage (or reduction in serviceability) as one application of an 80 kN single axle.

This AASHO Road Test concept is applied in the conversion of a mixed truck traffic stream of different axle loads and axle configurations into a common denominator, the 80 kN ESAL. The truck traffic stream, mix, and loads for the project are converted to an equivalent number of 80 kN single axle loads for the design period. Finally, this sum is converted to a Traffic Index or TI which is used in the respective standard section selection or design procedures for portland cement concrete pavement and for asphalt concrete pavements, as described in Topics 607 and 608. Derivation of the TI is covered in Index 603.4.

Unfortunately, for the purpose of pavement structural section design, the development of truck traffic projections is not always a simple straight line projection of available data. This is especially true in areas where there are rapid growth patterns and changing land use. Since the early 1970's, there has been a growing trend to allow local planning agencies a more influential role in the planning of the State highways including the Interstate routes down to the project level. This has been especially true where regional or local planning agencies have developed or adopted traffic models (developed by others) which are used to project traffic growth.

The Caltrans Planning staffs are nevertheless responsible for developing traffic projections (including trucks) for the planning and design of State highways. In urban areas, it is generally most appropriate to obtain traffic projections from traffic models. Model input data should be in conformance with the adopted land use plan and Department of Finance population forecasts. Traffic forecasts made by regional or local agencies may be used as the basis of ESAL and subsequent TI determination if the District Division Chief for Planning is satisfied that the traffic model used is adequate for the purpose, model data and factors are appropriate, and that the land use plan and population requirements have been satisfied. On the other hand, where a project is on a new or upgraded route in a rural setting, with low traffic volumes, the development of projected traffic may be solely a straight line projection of available traffic data taken from the Traffic Volumes and the Annual Average Daily Truck Traffic booklets developed by the Caltrans Traffic Operations Program.

The Office of Transportation Analysis in the Planning Program should be notified by the District Division Chief for Planning if there is a significant difference between the traffic used to determine ESAL's and the traffic forecast by the regional agency.

603.2 Design Period

New pavement structural sections must be designed to carry the projected one-way truck traffic for a period of 20 years following its opening to traffic. When shorter design periods are proposed, they must be supported by documentation and submitted to OPPD for approval; see Index 602.1(3).

Because of the many independent variables involved, the service life before major maintenance or rehabilitation is required may actually be considerably longer or shorter than the design period. With the emphasis that is now placed on the incorporation of positive drainage into the pavement structural section, it is anticipated that the actual service life of pavements will generally exceed the design life. It is recognized, in the economic comparison of AC and PCC pavement structural sections (see Index 609.3), that ACP generally requires some significant maintenance or rehabilitation at 10 to 15 years of service while the PCCP will not generally require any significant work until or after the design period has transpired.

On AC facilities where it is anticipated that widening will occur within the design life of the pavement and when feasible, the AC pavement layer may be incrementally constructed (stage construction). The ACP structural section must still be designed for 20 years of service (i.e.: 20-year Traffic Index), however, the AC pavement layer may be appropriately reduced in thickness with the realization that a new AC surface layer will be placed concurrent with the future widening. Use of the stage construction strategy will be considered a “special” design and will require approval by OPPD, see Index 602.1(3). Also see Index 608.5 for shoulder design considerations if future roadway widening is potential. An economic analysis must also be performed to assist in project decisions.

603.3 Truck Traffic Projection

(1) *Mainline Traffic.* Considerable judgment is required to develop realistic traffic volume projections or expansion factors. The historical data that is most commonly used for truck traffic volume and loading projections by Caltrans comes from two routine statistical data gathering studies which are carried out by the Districts, under direction of the Traffic Operations Program, on a statewide basis. These are the Vehicle Classification Program and the Truck Weight Studies.

The first and most comprehensive of these data sources is the Vehicle Classification Program. Classification counts are made at many stations throughout the State Highway System on a rotating basis to develop a statistical data base from which the Annual Average Daily Truck Traffic (AADTT) information booklet is compiled for all routes. This booklet, which is published annually for statewide use, provides AADT for all vehicles; total truck AADT; the truck AADT for 2, 3, 4, and 5 or more axles; and the one way ESAL that would be generated by 50 percent of the two-way truck AADT reported in a one year period. This information is identified by kilometer post at selected count stations and is statistically interpolated for selected points in between.

The data obtained from the AADTT booklet may not be adequate to predict truck traffic for a specific project. Therefore, it is often necessary to take special counts on streets and highways at or near the project site. In addition, land use planning and other pertinent information should be considered in estimating increases in truck volumes and masses during the design period, especially where it is likely that there may be industrial or commercial expansion.

The second of the primary data sources is the Truck Weight Study, which is done in accordance with guidelines established by the FHWA. This is a biennial program that involves the weighing of trucks and recording of data at selected locations throughout the state to develop a statistical representation of the magnitude of axle loadings on the four axle configurations (2, 3, 4, and 5 or more) which are identified in the Classified Truck Counts.

OPPD uses this information to develop ESAL Constants that represent the estimated total accumulated ESAL, for each of the four axle configurations, during the design period. The current 10 and 20-Year ESAL Constants are shown in Table 603.3A.

Table 603.3A

ESAL Constants

Vehicle Type	10-Year Constants	20-Year Constants
2-axle trucks	690	1380
3-axle trucks	1840	3680
4-axle trucks	2940	5880
5-axle trucks or more	6890	13 780

The ESAL Constants are used as multipliers of the expanded AADTT to determine the total design period ESAL's and in turn the Traffic Index (TI). The ESAL's and the resulting TI are the same magnitude for both AC and PCC pavement design alternatives.

The distribution of truck traffic by lanes must be considered in the structural section design for all multilane facilities. It is readily apparent that the distribution by lanes varies widely depending on a number of factors including overall traffic volumes, number of lanes, location (urban or rural), proximity of ramps to and from commercial and industrial areas, etc. Truck traffic is generally lightest in the median lanes with progressive increases toward the outside lanes. At locations with closely spaced on-ramps and off-ramps, during heavy traffic periods the lane next to the outside lane becomes the heavy truck traffic lane. Also, unusual events such as accidents, slides, slipouts, and maintenance and repair work create unpredictable shifts of traffic between lanes. In addition, future widening may create a permanent shift in lane distribution during the design life of the pavement structural section. Because of the uncertainties and the variability of lane distribution of trucks, arbitrary lane distribution factors have been established for design purposes as shown in Table 603.3B.

Table 603.3B

Lane Distribution Factors for Multilane Roads

Number of Lanes in One Direction	Factors to be Applied to Expanded Average Daily Trucks			
	Lane 1	Lane 2	Lane 3	Lane 4
One	1.0	-	-	-
Two	1.0	1.0	-	-
Three	0.2	0.8	0.8	-
Four	0.2	0.2	0.8	0.8

NOTES:

1. Lane 1 is next to the center line or median.
2. For more than four lanes in one direction, use a factor of 0.8 for the outer two lanes and any collector lanes and a factor of 0.2 for all other lanes.

Finally, an expansion factor is developed for each axle classification. In its simplest form, the expansion is a straight-line projection of the AADTT data. When using the straight-line projection the data is projected to find the AADTT at the middle of the design period, thus representing the average AADTT for each axle classification for the design period. The expanded AADTT, for each axle classification, is multiplied by the appropriate lane distribution factor (fraction of the total AADTT) to arrive at the expanded AADTT for the lane. The lane AADTT is multiplied by the design period ESAL constant for each corresponding axle classification. Finally, the summation of these totals equals the total one-way ESAL's for the lane which is converted into the TI for the lane.

When other than a straight-line projection of available truck traffic data is used for design purposes, the procedure to be followed in developing traffic projections will vary. It will be dependent on a coordinated effort of the District's Planning and Traffic Divisions working closely with the Regional Agencies.

(2) *Shoulder Traffic.* AC shoulders adjacent to the outer lane (with either AC or PCC pavements on the mainline) are designed for the TI determined from 2% of the ESAL of

the outer lane, however, a TI less than 5.0 should not be used. The design of inner shoulders is covered under Index 603.3(5) and Index 608.5. When PCC pavement and shoulders are used, the design is a standard structural section as covered in Topic 607.

(3) *Ramp Traffic.* Estimating future truck traffic on ramps is more difficult than on through traffic lanes. The relative effect of commercial and industrial development of an area is much greater on ramp truck traffic than it is on mainline truck traffic.

Ramp traffic is relatively more destructive to pavement than through traffic because of the greater amount of acceleration and deceleration that occurs. The sharper curvature and steeper grades normally encountered on ramps also contribute to the increased destructive effect of traffic.

Repair of the structural section elements of ramps usually requires more complex traffic control procedures, especially in urban areas. In order to minimize the potential congestion, traffic delay, highway workers exposure to traffic, and out-of-the-way travel, ramps especially in urban or industrial areas should be designed for a higher TI than that determined from a projected ramp AADTT.

As an alternative to estimating and projecting an AADTT to determine the ramp TI, ramps may be classified and designed as follows:

(a) Light Traffic Ramps - Ramps serving undeveloped and residential areas should be designed for a TI of 8.0.

(b) Medium Traffic Ramps - Ramps in metropolitan areas, business districts, or where increased truck traffic is quite likely to develop because of anticipated commercial development within the design period should be designed for a TI of 10.0.

(c) Heavy Traffic Ramps - Ramps that serve weigh stations, industrial areas, truck terminals, and/or maritime shipping facilities during the design period should be designed for a TI of 12.0.

When ramps are widened to handle truck off-tracking, the full structural section, based on the ramp TI, should be extended to the inner edge of the required widening, see 504.3(1)(b).

(4) *Auxiliary Lane Traffic.* Because of structural section drainage considerations, the auxiliary lane structural section should have the same thickness for the pavement, base, and subbase layers as those specified for the adjoining outer lane of the traveled way.

(5) *Median Shoulder Traffic.* Paved medians are subject to occasional use by maintenance trucks and other heavy maintenance vehicles. Occasionally, disabled heavy commercial vehicles or emergency vehicles may use the median. Generally, medians less than 3.6 m in width on all paved 4-lane cross sections are constructed with the same structural section as the median traveled way lane. Median shoulders on 4-lane divided highways are arbitrarily paved with 60 mm of AC over a variable AB thickness.

When there is a potential for restriping to add a lane or lanes to carry mainline or high occupancy vehicle traffic, an estimate of traffic should be made. This and other pertinent factors should be considered in determining the structural section under the median shoulder.

603.4 Traffic Index

The Traffic Index or TI is a measure of the number of ESAL's expected in the design lane over the design period. The TI does not vary directly with the ESAL's but rather according to the following exponential formula and as illustrated in Table 603.4A.

$$TI = 9.0 \times (ESAL/10^6)^{0.119}$$

Where:

TI = Traffic Index

ESAL= Equivalent 80 kN Single Axle Loads

Table 603.4B illustrates the determination of the TI for outside and median lanes of an 8-lane freeway. The expanded AADTT and the TI's shown in Table 603.4B are taken from the flexible pavement design example (described in Index 608.4) and are not intended to be used in the design for a specific project.

Table 603.4A
Conversion of ESAL to Traffic Index

ESAL	TI*	ESAL	TI*
48		1 270 000	
	3.0		9.5
194		1 980 000	
	3.5		10.0
646		3 020 000	
	4.0		10.5
1850		4 500 000	
	4.5		11.0
4710		6 600 000	
	5.0		11.5
10 900		9 490 000	
	5.5		12.0
23 500		13 500 000	
	6.0		12.5
47 300		18 900 000	
	6.5		13.0
89 800		26 100 000	
	7.0		13.5
164 000		35 600 000	
	7.5		14.0
288 000		48 100 000	
	8.0		14.5
487 000		64 300 000	
	8.5		15.0
798 000		84 700 000	
	9.0		15.5
1 270 000		112 000 000	

*NOTE:
The determination of the TI closer than 0.5 is not justified. No interpolations should be made.

Table 603.4B
Example Determination of the 20 Year Traffic Index for an 8-lane Freeway

		Outside Lanes		Median Lanes	
(1) Vehicle Type	(2) ESAL 20 Year Constants	(3) Expanded Average Daily Trucks	(4) Total 20 Year ESAL (Col.2 x Col.3)	(5) Expanded Average Daily Trucks	(6) Total 20 Year ESAL (Col.2 x Col.5)
2-axle trucks	1380	935	1 290 300	235	324 300
3-axle trucks	3680	550	2 024 000	140	515 200
4-axle trucks	5880	225	1 323 000	55	323 400
5-axle or more	13 780	1025	14 124 500	255	3 513 900
Totals	----	----	18 761 800	----	4 676 800
Traffic Index (TI) for 20 Year Design, From Table 603.4A =			12.5		11.0

Topic 604 - Basement Soils

604.1 Introduction

The resistance value (R-value) is a parameter representing the resistance to deformation of a saturated soil under compression at a given density. The R-value is measured with the stabilometer, and is used in the design of flexible and rigid pavements. It is an indication of the ability of the soil to carry the dead load of the structural section and the superimposed traffic live load.

Almost all compacted soils have a tendency to expand when given access to water. As soils expand and take on water, the load supporting ability decreases, as indicated in laboratory tests by a decreasing R-value. Thus, a prescribed expansion pressure apparatus is used to verify the basement soil R-value as needed for both flexible pavement and for portland cement concrete pavement (PCCP).

The amount of expansion created by increased moisture content and the consequent loss of density is limited by the overlying dead load of the structural section materials placed over the soil. When the loading pressure of the overlying material and the expansive forces within the soil become equal, the expansion is halted and no further loss of R-value occurs. Then the soil is in the most unstable state it will reach with the given dead load pressure of the overlying structural section layers. Under these conditions, the structural section design thickness and strength must be sufficient to protect the soil in question from differential deformation or displacement from the traffic live loads. In addition, the thickness of cover, provided by the structural section, must apply adequate deadload pressure to prevent further expansion which would result in decreased stability.

If the soil is identified as potentially expansive, special design and construction considerations should be given. Design alternatives which have been used to compensate for expansive soils are:

(a) Treating expansive soil with lime or other additives to reduce expansion in the presence of moisture, or

(b) Replacing the expansive material with a non-expansive material to a depth below which the seasonal moisture content will remain nearly constant, or

(c) Providing an overlaying structural section of sufficient thickness to counteract the expansion pressure by dead-load pressure (surcharging), or

(d) Using two-stage construction by placing a thin structural section to permit the underlying material to expand and stabilize before placing leveling and surface courses, or

(e) Stabilizing the moisture content by minimizing the access of water through surface and subsurface drainage and the use of a waterproof membrane (i.e., geotextile fabrics or rubberized asphalt membrane), or

(f) Relocating the project alignment to a more favorable soil condition.

Treatments (a), (b), (c), and (d) should be used with caution since undesirable soil expansion has occurred on some projects where these methods were used. Treatment (e) is considered to be the most effective approach if relocation is not feasible. METS will assist, upon request, to select the most appropriate method of treating expansive soils for individual projects.

If the soil is non-expansive, the R-value for design is based on the presumption that the soil will become saturated at some time during its service life. This procedure indicates the lowest strength condition that will most likely occur during this period. The use of positive subgrade and structural section drainage systems will minimize the duration of a saturated lowest-strength condition. A positive structural section drainage system, as covered in Indexes 606.2 and 606.3, will serve to minimize water-related structural section damage.

604.2 Determination of Design R-Value

R-values of soils to be encountered on a project are provided in the Materials Report. Considerable variation in these values within project limits is quite common. Since a design R-value must be chosen for design of the structural section, it is important to know the extent of material represented by the various R-value tests.

Since a wide variation of materials types and deposits found within project limits are quite common, it is not practical to establish hard and fast rules for selecting a design R-value. Increased emphasis on the provision of positive structural section drainage, as discussed in Topic 606, allows a more liberal approach (than in the past) to the selection of design R-values. Judgment based on experience should still be exercised to assure a reasonably "balanced design" which will avoid excessive costs resulting from over conservatism. Examples from the past should be used only as indicators of potentially good or bad practice.

If the range of R-value is small or if most of the values are in a narrow range with some scattered higher values, the lowest R-value should be selected for the structural section design. The lowest R-value should not, however, necessarily govern the structural section design throughout the length of long projects. If there are a few exceptionally low R-values and they represent a relatively small volume of basement soil or they are concentrated in a small area, it may be possible to specify placing this material in the bottom of an embankment or in the slope area outside the structural section limits. Occasionally lime treatment of a short length may be cost effective.

Experimental test section performance indicates that the use of geotextiles (engineering fabrics) may allow the designer to select a higher R-value for structural section design where basement soils are variable and areas of isolated low R-value materials ($\leq$ 20) are difficult to locate. The placement of geotextiles below the structural section will provide subgrade enhancement by bridging soft areas and providing a separation between soft pumpable subgrade fines and high quality subbase or base materials. The Pavement Consulting Services Branch of METS can assist in the selection and use of geotextiles for this application.

Where changing geological formations and soil types are encountered along the length of a project, it may be cost-effective to design more than one structural section to accommodate major differences in R-value that extend over a considerable length. Care should be exercised, however, to avoid multiple variations in the structural section design that may actually result in increased construction costs that exceed potential materials cost savings.

604.3 Borrow

Local or imported borrow is used to make up for deficiencies in available quantities of excavation material to construct embankments. The R-value of the excavated material on the project is generally specified as the minimum for the borrow. When borrow material of this quality is not economically available or when all of the earthwork consists of borrow, the R-value specified for the borrow becomes the design R-value. Since no minimum R-value is required by the Standard Specifications for local borrow, a minimum must be specified by Special Provision (SP) to cover material placed within 1.2 m of the finished grade.

604.4 Compaction

The Standard Specifications require 95 percent relative compaction of untreated bases, sub-bases, and earthwork for a minimum depth of 200 mm below the grading plane. This requirement should not be modified by special provision.

In addition, the Standard Specifications require not less than 95 percent relative compaction be obtained for a minimum depth of 800 mm below finished grade for the width of the traveled way and auxiliary lanes plus 1 m on each side. This specification is sometimes waived by SP, with OPPD approval, when such action is justified in accordance with Index 602.1(3). Acceptable reasons for a waiver are:

(a) A portion of a local road is being replaced with a stronger structural section, or

(b) Partial-depth reconstruction is specified, or

(c) Existing buried utilities would have to be moved, or

(d) Interim widening projects are required on low volume-roads, intersection channelizations, or frontage roads.

In addition to the submittal instructions referred to above, the location(s) where the SP applies should be shown on the typical cross section(s). The 800 mm depth of compaction should not be waived for the traveled way or auxiliary lanes of State highways, freeways, or for freeway ramps.

Topic 605 - Subbases and Bases

605.1 Introduction

The characteristics of various subbases and bases that may be used in structural sections are discussed in the following text. Generally, these subbases and bases may be used in various combinations to design the most economical structural section for the specific project. Standard structural sections are used for portland cement concrete pavement (PCCP) with optional base and subbase combinations.

Because different types of treated and untreated aggregates have different capacities for resisting the forces imposed by traffic, this factor must be considered when determining the thickness of the structural section elements. This is accomplished with gravel factors (G_f) which express the relative value of various materials when compared to gravel. It is important to note that the various materials must meet the specified quality requirements, such as grading, to ensure the validity of the assigned gravel factor. Gravel factors for the various types of base materials are provided in Table 605.1.

Since pavement design is a continually evolving field, the following text is not intended to rule out new materials or procedures which may be developed. The METS may be contacted for the latest in subbase and base materials and related design considerations.

605.2 Aggregate Subbase (AS)

Aggregate subbase (AS) is normally specified as the lowest element of any structural section because it generally results in the most economical design. It may consist of more than one layer. Whenever the basement soil has an

Table 605.1
Subbases and Bases

Type of Material[1]	Abbreviation	Gravel Factor (G_f)	Design R-Value
Aggregate Subbase	AS-Class 1	1.0	60
	AS-Class 2	1.0	50
	AS-Class 3	1.0	40
	AS-Class 4	1.0	specify
	AS-Class 5	1.0	specify
Aggregate Base	AB-Class 2	1.1	78
	AB-Class 3	1.1[2]	specify
Asphalt Treated Permeable Base	ATPB	1.4	NA
Cement Treated Base	CTB-Class A	1.7	NA
	CTB-Class B	1.2	80
Cement Treated Permeable Base	CTPB	1.7	NA
Lean Concrete Base	LCB	1.9	NA
Lime Treated Subbase	LTS	$0.9 + \frac{UCS}{6.9}$	NA

Notes:

1. For Asphalt Concrete Base (ACB), see Index 605.7.
2. Must conform to the quality requirements of AB-Class 2.

Legend:

NA = Not Applicable

UCS = Unconfined Compressive Strength in MPa

R-value of 40 or more or whenever the normal design process results in a thin layer of subbase, consideration should be given to eliminating the subbase layer and designing a thicker base. The decision is generally based on the lowest initial cost, since both designs should be structurally equal.

Whenever a blanket of permeable material is required under the full width of the structural section to handle subsurface water, the permeable layer is considered as subbase in the design calculations.

605.3 Aggregate Bases (AB)

Untreated aggregate bases may be used under AC pavement when economical. When an untreated aggregate base is proposed for use with AC pavement, its use in lieu of a treated permeable base (TPB) must be justified in accordance with Index 606.2(3). It can be used below the TPB layer but its surface should be stabilized with an asphalt prime coat.

605.4 Stabilized Bases and Subbases

Asphalt, portland cement, a combination of portland cement and pozzolanic materials, lime, and other cementing or stabilizing agents can be combined with selected aggregate or soils or with native materials to improve their stability and strength as load carrying elements of the structural section. The use of such materials depends on a number of variables including relative cost and availability of materials, native material types, environmental conditions, traffic projections, and established standards and practices.

Asphalt or cement may be used to improve low-quality aggregates for use as base or subbase material.

The type and amount of stabilizing agent should be developed from tests of available materials and then cost comparisons made against untreated specification aggregates.

605.5 Cement Treated Bases (CTB)

Cement treated base (CTB) is generally used only with asphalt pavements and is specified in two classes described as follows:

(a) Class A CTB consists of aggregate mixed with sufficient cement to produce a base with considerable slab strength. Class A CTB is used directly under AC to provide added strength under heavy truck traffic or placed directly below a TPB.

(b) Class B CTB consists of aggregate with an R-value of not less than 60 which is mixed with cement in an amount sufficient to raise the R-value to not less than 80.

Either Class A or Class B CTB may be used with asphalt concrete pavements to increase its load carrying capacity and durability. Due to the slab strength of Class A and the high stability of Class B, use of either is often the most economical choice over aggregate bases because less base thickness is required.

CTB can be plant-mixed or road-mixed. Plant mixing is preferred, but road-mixing is permitted when quantities are too small to make plant-mixing cost effective. Road-mixing should be justified in the Geotechnical Design Report or Materials Report, as applicable.

Where cohesionless sand is used as subbase under a cement-treated base, it is necessary to provide a “working table” of aggregate subbase, aggregate base or cement treated base aggregate. This “working table” normally will be from 75 mm to 105 mm thick to provide for the proper construction of the cement-treated base. The “working table” is considered as a subbase material in the design.

605.6 Lean Concrete Base (LCB)

Lean concrete base (LCB) was developed to provide a more rigid, less erodible base than the traditional Class A CTB for use under PCCP. The use of LCB reduces the effect of pumping action and resultant step-faulting in PCCP. LCB is a concrete mixture of aggregate mixed with about one-half the cement content of conventional concrete.

The advantages of LCB as compared to CTB include:

(a) LCB has greater long term strength than CTB,

(b) The same slip-form paving equipment used for placement of PCCP may be used to place the LCB,

(c) LCB may be placed to more accurate grade tolerances, and

(d) Most important, the LCB surface is harder and is less subject to the erosion that contributes to step-faulting created by pumping action of truck traffic on the PCCP.

605.7 Asphalt Concrete Base (ACB)

Although frequently referred to as a separate item, asphalt concrete base (ACB) is a plant-mixed dense-graded asphalt concrete that is similar to that used for the surface course, except that a coarser aggregate grading may be specified for added stability. ACB is designated as Type A or Type B, depending on the quality of the aggregate. Type A is primarily a crushed aggregate, which provides greater stability than Type B.

When used with portland cement concrete pavement, the ACB is to be placed in the thicknesses shown in Table 607.2.

When used with asphalt concrete pavement (ACP), the ACB is to be considered as part of the pavement layer. The ACB will be assigned the same G_f as the remainder of the AC in the structural section.

605.8 Treated Permeable Bases (TPB)

Treated permeable bases (TPB) are mixtures of high quality coarsely graded crushed aggregate and a binder material. The binder material may be either asphalt or portland cement. The decision to use either asphalt treated permeable base (ATPB) or cement treated permeable base (CTPB) is based primarily upon economic considerations and materials availability. The option chosen is generally the PE's decision for ACP. When PCCP is used, the option (cement or asphalt treated) will be the contractors at the time of bid based upon construction economics and materials availability.

TPB provides a highly permeable drainage layer within the structural section. The permeable base extends laterally from 0.3 m outside the edge of pavement on the high side to the outside edge of the collector trench on the low side of the structural section, see Figure 606.2A. The TPB layer is an integral part of the structural section and provides all or part of the strength function normally required of the base layer.

605.9 Lime Treated Subbase (LTS)

Some soils, when treated with lime, will form cementitious compounds resulting in a relatively high strength material. When this cementing results in an unconfined compressive strength (USC) of 2.75 MPa or greater, as determined by California Test 373, it can provide a satisfactory, economical substitute for AS. On light duty roads a lime treated soil may also provide a satisfactory base layer.

The gravel factor for LTS is calculated from the UCS of the treated soil measured in MPa using the formula:

$$G_f = 0.9 + \frac{UCS}{6.9}$$

Topic 606 - Drainage of the Pavement Structural Section

606.1 Introduction

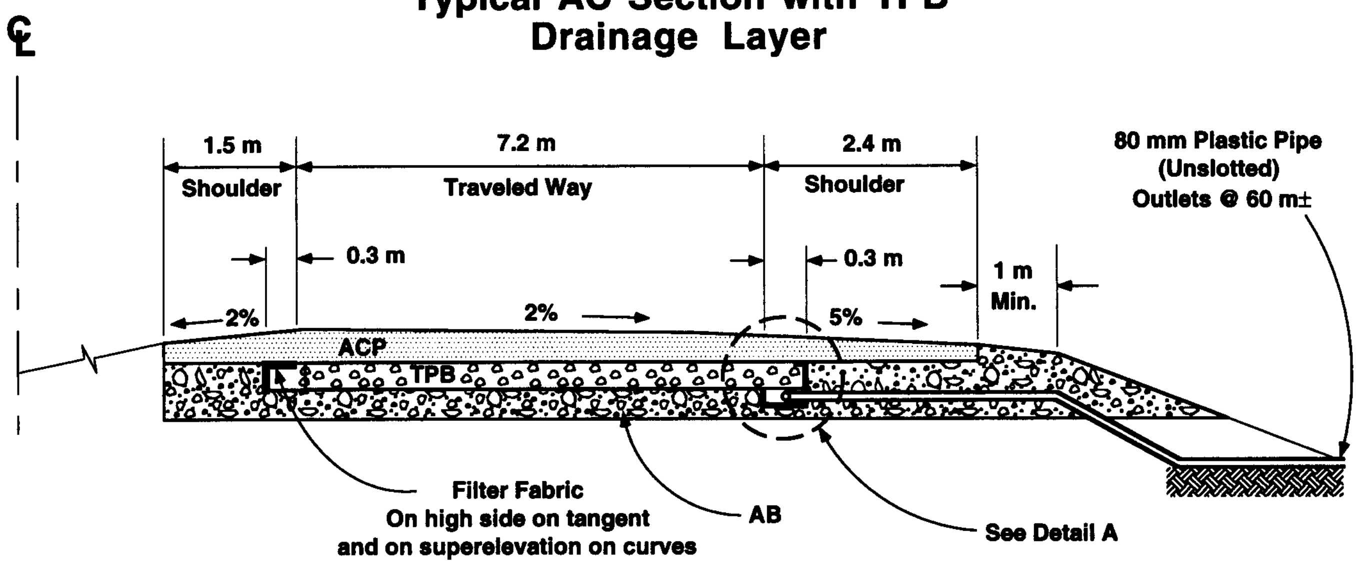
Premature distress in both flexible and rigid pavements is generally caused by exposure to heavy truck traffic when the pavement structural section is in a saturated condition. Saturation of the structural section or underlying foundation materials or both generally results in a decrease in strength or ability to support heavy truck axle loads. Potential problems associated with saturation of the structural section and the subgrade foundation include pumping action, differential expansion (swelling) of subgrade soils, frost damage in freeze-thaw areas, erosion and piping of fine materials creating voids which result in the loss of subgrade support, icing of pavement surface from upward seepage, stripping of asphalt concrete aggregates, and accelerated oxidation of asphalt binder. Rapid removal of water from the structural section is essential and is generally dependent on the inclusion of a positive drainage system.

606.2 Flexible Pavement Structural Section Drainage

(1) General Background. Water can enter into flexible pavement as surface water through cracks, joints, and asphalt concrete infiltration and as groundwater from an intercepted aquifer, a high water table or a localized spring. The saturation of, or the

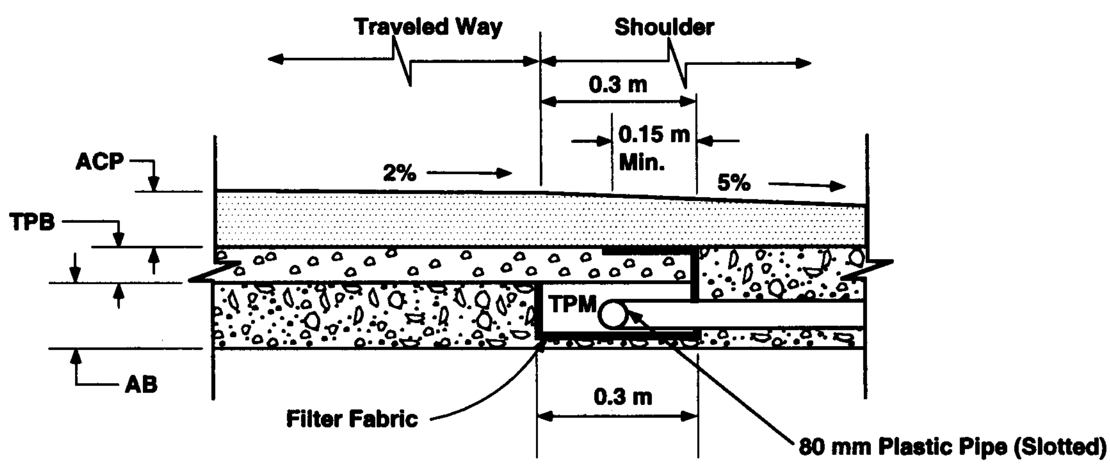
Figure 606.2A

Typical AC Section with TPB Drainage Layer



NOTES: 1. Section shown is a half-section of a divided highway. An edge drain collector and outlet system should be provided on both sides of 2-way crowned section.

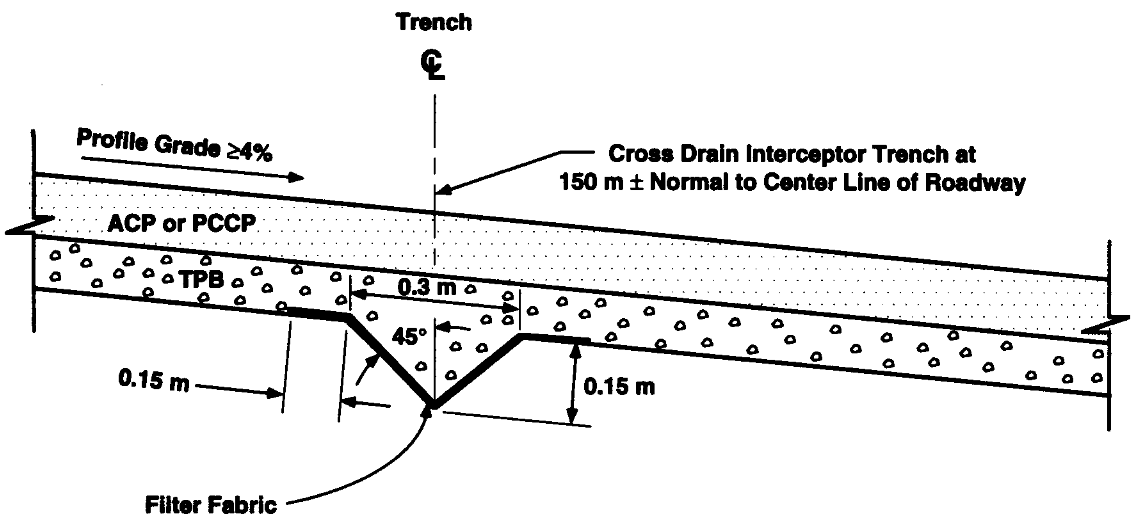
2. This figure is only intended to show typical pavement structural section details, for geometric cross section details, see Chapter 300.



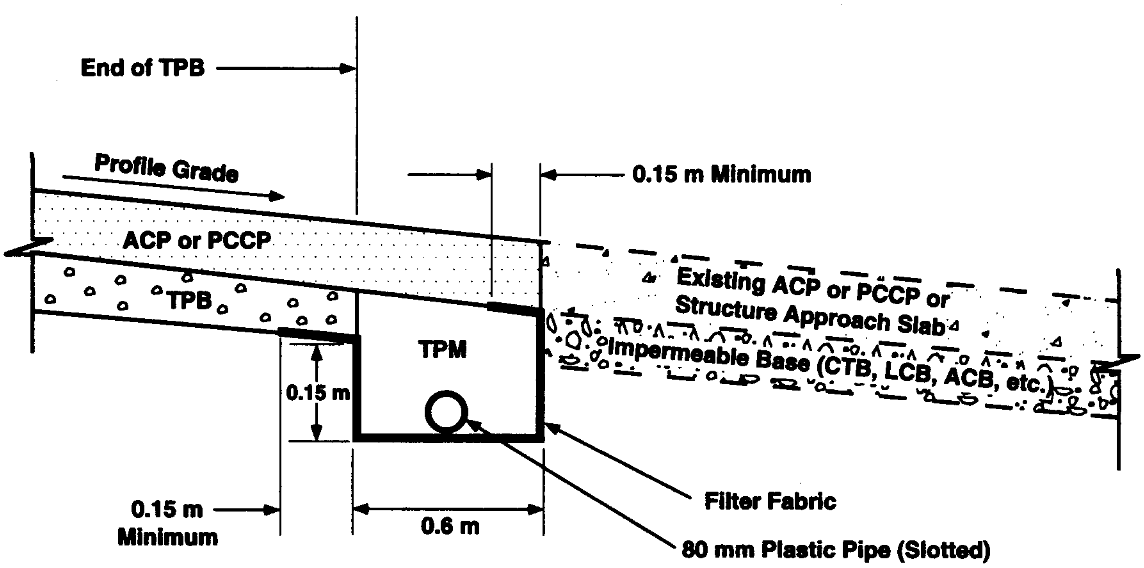
Detail A

Figure 606.2B

Cross Drain Interceptor Trenches



Intermediate Cross Drain
(Longitudinal Section)



Terminal Cross Drain
(Longitudinal Section)

presence of, water in the pavement structural section decreases the supporting strength, or load-carrying capacity, of succeeding untreated layers underlying the AC. This results in increased deflection under heavy wheel-loads, thereby leading to structural cracking and a pumping action which accelerates the fatigue failure of AC.

Both sources of water should be considered and provisions should be made to handle both. Estimated surface water inflow added to estimated groundwater inflow equals the total inflow to be removed by positive drainage systems. The structural section drainage system, which is designed to handle surface water inflow, is generally separate from the subsurface drainage system that is designed to accommodate encroaching groundwater. The estimated groundwater inflow can be determined by a combination of field investigations, analytical techniques and graphical methods. "Subsurface Drainage" is discussed in Chapter 840. An analytical method to estimate surface water inflow is discussed in Index 606.2(3).

The Geotechnical Design Report or Materials Report for a project will provide pertinent information and recommendations regarding both groundwater and surface water as appropriate. The District Materials Engineer and METS Pavement Consulting Services Branch may be contacted for assistance in developing appropriate features in the plans and specifications to address the problem of water in the structural section. The remainder of this index relates to the flexible pavement structural section drainage system that is required to drain surface water that enters the structural section.

(2) *Drainage Components and Related Design Considerations.* Rapid drainage of a pavement structural section is essential to minimize the length of time the structural section is saturated. This can best be achieved by placing a highly permeable drainage layer system under the full width of the pavement surface during initial construction. The basic components of a flexible pavement structural section drainage system are:

(a) A highly permeable drainage layer.

(b) A collector system.

(c) Outlets, vents, and cleanouts.

(3) *Drainage Layer*. A drainage layer consisting of either 75 mm of asphalt treated permeable base (ATPB) or 105 mm of cement treated permeable base (CTPB) should be placed immediately below the AC pavement for interception of surface water that enters the structural section. Exceptions, such as for areas where mean annual rainfall is very low (< 125 mm) or where the basement soil is free draining (a permeability $\geq$ 3.53 x 10^{-4}m/s) must be justified in the structural section submittal (See Index 602.1). The drainage layer is extended laterally from 0.3 m outside the edge of traveled way on the high side to the edge of the collector trench on the low side. A typical AC section with a treated permeable base (TPB) is shown in Figure 606.2A.

When there is concern that the infiltrating surface water may saturate and soften the underlying subbase or subgrade (due either to exposure during construction operations or under service conditions) a prime coat or other suitable membrane should be utilized. It should be applied to the base, subbase, or subgrade on which the TPB layer is placed to prevent erosion of the underlying material.

Either of the standard ATPB or CTPB layers (75 mm and 105 mm respectively) will generally provide greater drainage capacity than is needed under AC pavements. The standard thicknesses are based primarily on constructability with an added allowance to compensate for construction tolerances. Under a unique combination of conditions, such as where the infiltration rate exceeds 15 mm/h and the pavement is very wide (4 lanes or more on a single cross slope), the following procedures may be used to determine the necessary layer thickness. If material other than ATPB or CTPB with a different permeability is used under such conditions, it is necessary to check the adequacy of the layer thickness.

The estimated quantity of surface water that will penetrate the AC pavement (Q in m^3/s/m of roadway) may be determined by the equation:

$Q = IW / 3.6 \times 10^6$

Where:

W = width, in meters, of the drainage layer measured normal to the center line, and

I = the infiltration rate, in millimeters per hour.

In Table 606.2 are "design infiltration rates" for each District, which may be used in the event other than the standard 75 mm ATPB layer or the 105 mm CTPB layer is used.

Table 606.2
Design Infiltration Rate

District	I (mm/h) to be used in: $Q = \frac{IW}{3.6 \times 10^6}$	
1	8	
2	8	for Modoc County use 5
3	5	for Rte 49 and east use 8
4	10	
5	8	
6	8	
7	8	
8	10	
9	5	
10	5	for Rte 49 and east use 8
11	8	
12	8	

Note: These values were developed for each District using the average mean annual rainfall and the average Mean One-hour Storm (taken from California Department of Water Resources Bulletin 195, dated October 1976).

If local rainfall data is available for the project site the following equation may be used to determine the infiltration rate, "I" :

I = (0.33)(design hourly rainfall intensity)

The required thickness, t (in mm), of the drainage layer may be calculated using the equation:

$$t = \frac{1000Q}{ks}$$

Where:

k = the permeability of the material used in the drainage layer, in meter per second (0.0529 m/s for ATPB, and 0.014 m/s for CTPB), and

s = the pavement cross slope, in meter per meter.

First, 25 mm is added to the calculated permeable layer thickness to compensate for possible contamination during construction and to allow for construction tolerances, then the total thickness is determined by rounding up to the nearest 15 mm.

(4) *Collector System.* A 80 mm slotted plastic pipe should be installed in a longitudinal collector trench as shown in Figure 606.2A. In areas where the profile grade is equal to or greater than 4%, intermediate cross drain interceptors, as shown in Figure 606.2B should be provided at an approximate spacing of 150 m. This will limit the longitudinal seepage distance in the drainage layer, thereby minimizing the drainage time and preventing the buildup of a hydrostatic head under the AC surface layer. Cross drain interceptor trenches must be sloped to drain.

In addition, a cross drain must be provided at the low-end terminal of TPB projects, as shown in Figure 606.2B. Care should be taken to coordinate the cross drains with the longitudinal structural section drainage system. Drainage layers in roadway intersections and interchanges may require additional collector trenches, pipes, and outlets to assure rapid drainage of the structural section.

A standard longitudinal collector trench width of 0.3 m has been adopted for new construction to accommodate compaction and consolidation of the Treated Permeable Material (TPM) alongside and above the 80 mm slotted plastic pipe. The TPM type (cement or asphalt treated) for use in the collector trenches will be at the contractors option.

Filter fabric should be placed as shown in Figures 606.2A and 606.2B, to provide protection against clogging of the TPM by intrusion of fines.

On curvilinear alignments, superelevation of the roadway may create depressions at the low side of pavement where the collected water can not be drained away. An adjustment to the profile grade may be necessary to eliminate these depressions.

When a superelevation cross slope begins to drain the water through the TPB to the low side of pavement, the edge drain at the high side of superelevation is no longer required. Conversely, as the superelevation transition returns to the normal roadway cross slope, the standard edge drain should begin to collect water flowing back to the original low side of pavement.

(5) *Outlet Pipes.* Plastic pipe (unslotted) outlets should be provided at proper intervals for the pavement structural section drainage system to be free-draining. The spacing of outlets (including vents and cleanouts) should be limited to approximately 60 m.

The trench for the outlet pipe must be backfilled with material of low permeability, or provided with a cut-off wall or diaphragm, to prevent piping.

The outlets must be daylighted, connected to culverts or drainage structures, or discharged into gutters or drainage ditches. The area under the exposed end of a daylighted outlet should have a splash block or be paved to prevent erosion and the growth of vegetation which will impede flows from the outlet. Ready access to outlets, and the provision of intervening cleanouts when outlet spacing exceeds a maximum distance of 75 m, should be provided to facilitate cleaning of the structural section drainage system. Typical details are shown on the Standard Plans for Edge Drain Outlet and Vent Details.

The end of each outlet pipe should be indicated by an appropriate marker to facilitate location and identification for maintenance purposes and to reduce the likelihood of damage by vehicles and equipment. Consult the District Division of Maintenance for the preferred method of identification.

(6) *Cross Drain Interceptors.* When using TPB, special attention should be given to drainage details wherever water flowing in the TPB encounters impermeable abutting pavement, a bridge approach slab, a sleeper slab, a pavement end anchor, or a pressure relief joint. In any of these cases, a cross drain interceptor should be provided.

Details of cross drain interceptors at various locations are shown in Figure 606.3. The cross drain outlets should be tied into the longitudinal edge drain collector and outlet system with provision of maintenance access for cleaning.

(7) *Structural Section Design Considerations.* The normal flexible pavement design procedure, as covered under Index 608.4, is followed to develop AC pavement structural sections which incorporate a drainage layer to accommodate surface infiltration. A gravel factor (G_f) of 1.4 is used for ATPB with a standard thickness of 75 mm. A standard thickness of 105 mm is used for CTPB with a G_f of 1.7. Because of their relative rigidity, no R-value is assigned to either ATPB or CTPB and the design is handled in the same manner as described for Class A CTB in the structural section design procedure, see Index 608.4(6).

606.3 Rigid Pavement Structural Section Drainage

(1) *General Background.* The lack of adequate structural section drainage for concrete pavement has become increasingly evident. Extensive research of concrete pavement performance, both in the field and in the laboratory, has revealed that the primary cause of deterioration is the trapping and retention of surface water inflow, in a "choker" or "bathtub" type section, coupled with exposure to heavy truck axle loading. This combination creates the potential for severe pavement damage, especially in heavily traveled truck lanes. Heavy trucks depress the edges of curled slabs at the transverse joints. When the structural section is saturated, the resultant pumping action results in the erosion of the cement treated base (CTB) or aggregate subbase (AS), which were specified for the construction of concrete pavement in California from about 1950 to the late 1970's. In addition, the pumping action along the outer edge of the pavement has resulted in the erosion and movement of fine

materials from the existing aggregate base under the adjoining shoulders. The fine materials from both sources are transported by pumping action and deposited under the trailing edge of the pavement slabs, resulting in step faulting, uneven slab support, and slab rocking and cracking. Failure of the inner edge of the shoulder also results from loss of aggregate base support.

(2) *Current Base Standards.* In an effort to provide positive drainage and minimize base erosion and resultant slab faulting, edge drains and lean concrete base were adopted as standards for new construction in 1980. The current concrete pavement design standards (adopted in 1982), include a structural section drainage system. As shown in Table 607.2, the following four options are available to be used as bases in PCCP structural sections:

(a) Asphalt Treated Permeable Base (ATPB)

(b) Cement Treated Permeable Base (CTPB).

(c) Lean Concrete Base (LCB)

(d) Asphalt Concrete Base (ACB)

Because of their excellent drainage characteristics, the treated permeable bases must be given first consideration in the design of structural sections for concrete pavements. These cross sections are illustrated in Figures 607.2A and 607.2B and are detailed in the Standard Plans. Cross sections for dense base layers are also shown in Figures 607.2A and 607.2B.

In low lying agricultural areas or wetlands, pavement grade must be established at an elevation that will assure the rapid egress of water from the permeable base layer. If this is not practical, the use of permeable base may not be advisable. Edge drains should, however, be provided with either base type when the system can be positively drained.

(3) *Edge Drain Systems*. Edge drain collector and outlet systems (as shown in the Standard Plans for Structural Section Drainage) are to be provided for all four bases. The system includes a 80 mm diameter slotted plastic collector pipe, surrounded by treated permeable material, encapsulated in a filter fabric barrier to prevent contamination by the intrusion of fine materials from the adjoining untreated base or subbase.

Figures 607.2A and 607.2B show typical edge drain collector system details when either of the treated permeable bases (ATPB or CTPB) or either of the dense bases (LCB or ACB) are used.

When a dense base is used, the edge drain system should extend continuously along the outside edge of the truck lane and along the median lane edge when the median lane is on the low side of the superelevation, if positive drainage can be obtained. When a treated permeable base is used, the edge drain at the high side of superelevation may be discontinued as described in Index 606.2(4).

A 80 mm slotted plastic pipe with 3 rows of slots is the standard for edge drain systems. Desirable spacing of cleanouts or outlets is 60 m $\pm$ to accommodate cleaning. Longer runs between cleanouts or outlets significantly increase the required maintenance effort.

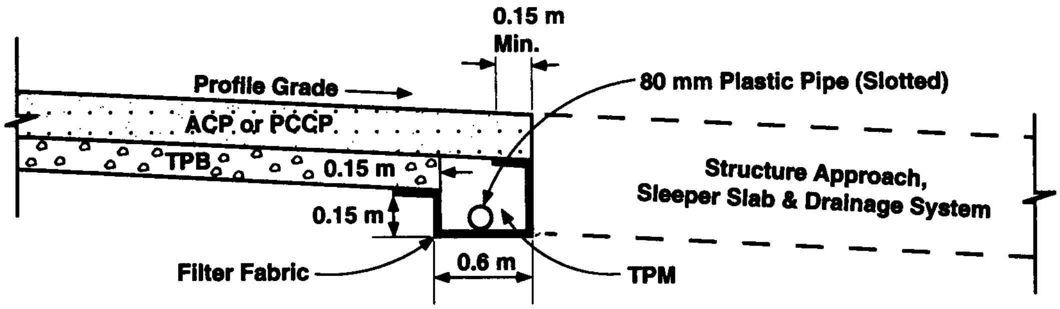
Edge drain cross section details for all PCC pavement-base-shoulder combinations are included in the Standard Plans.

Generally, the structural section drainage systems described above will provide for rapid drainage to minimize the time of saturation under heavy traffic. Drainage of groundwater should be handled by separate drainage systems, see Chapter 840. Allowing water to penetrate the structural section from below is not recommended.

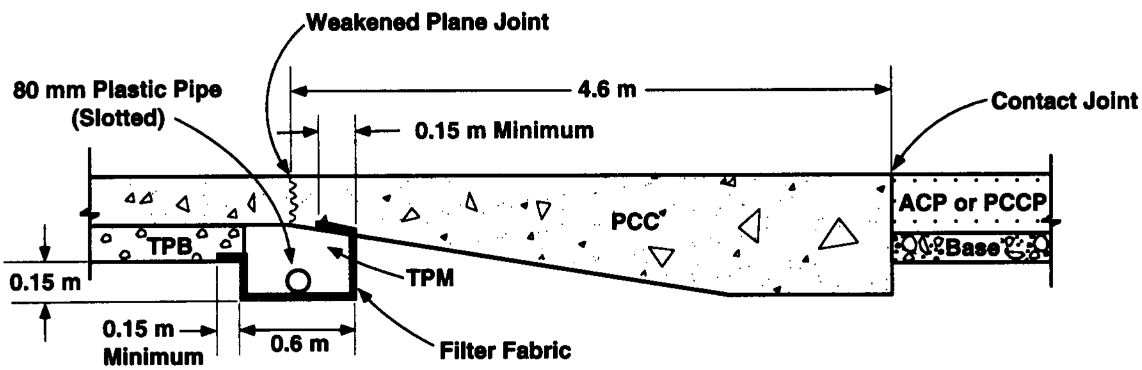
(4) *Cross Drain Interceptors.* When using TPB, special attention should be given to drainage details wherever water flowing in the TPB encounters impermeable abutting pavement, a bridge approach slab, a sleeper slab, a pavement end anchor, or a pressure relief joint. In any of these cases, a cross drain interceptor should be provided.

Details of cross drain interceptors at various locations are shown in Figure 606.3. The cross drain outlets should be tied into the longitudinal edge drain collector and outlet system with provision of maintenance access for cleaning.

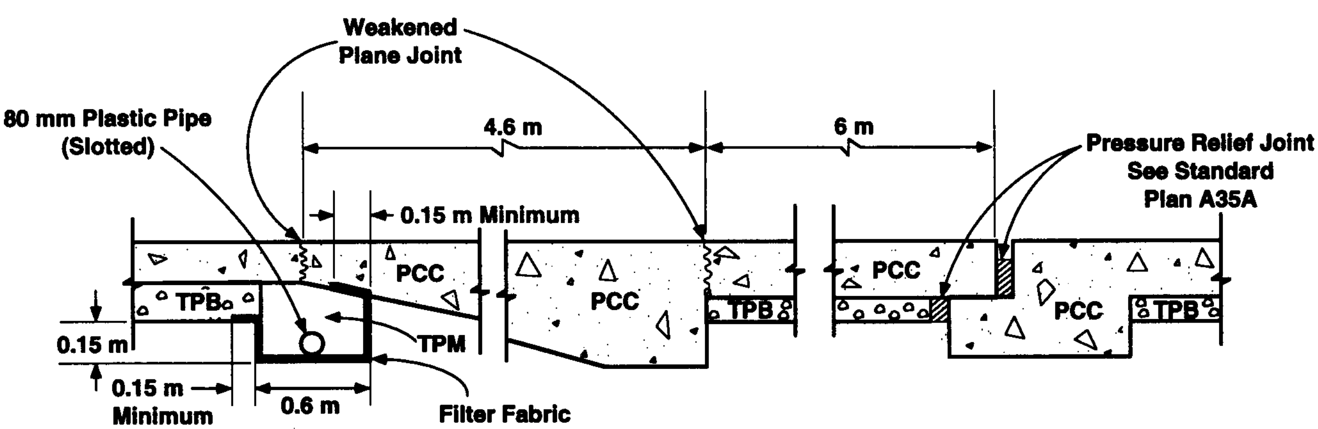
Figure 606.3
Cross Drain Interceptor Details
For Use with Treated Permeable Base (TPB)



AT STRUCTURE APPROACH
(Longitudinal Section)



AT END ANCHOR
(Longitudinal Section)



AT PRESSURE RELIEF JOINT
(Longitudinal Section)

Topic 607 - Portland Cement Concrete Pavement Structural Section Design

607.1 Introduction

Generally, the use of portland cement concrete pavement (PCCP) has been confined to moderate to high traffic volume freeways. A rational design method for the design of PCCP was adopted in 1967 with the hope that it would better relate the PCCP thickness to traffic loading and that it might result in the use of PCCP on a wider variety of facilities and ultimately in some long term cost and service benefits. It was found, however, that the rational design method did not reflect field conditions accurately and it was not sensitive to wide variations in truck traffic. The 1967 design method was replaced in 1982 by a series of standard structural sections that were later updated but are still current. These standard structural sections are based primarily on experience and research. A major change is that cement treated base (CTB), the traditional standard for PCCP (from 1950 to late 70's), is no longer considered to be appropriate for PCCP because of its susceptibility to erosion.

Some of the factors that were considered in adopting the current PCCP procedures include:

(a) Minimizing drainage related problems encountered in California on PCCP over the preceding 30 year period.

(b) Dropping the 1967 rational design method which did not represent actual field conditions or the pavement deterioration occurring in California.

(c) Offering the potential for cost savings: by elimination of subbase on high quality basement soil, and by elimination of base where the basement soil is free-draining.

(d) Offering the potential for use of PCCP, as an alternate to asphalt concrete pavement, on relatively low to medium truck traffic volume facilities (TIs from 6 to 10).

Under current procedures truck traffic and soil conditions are the principal factors considered in selecting the structural section. Standard structural sections are included for a range from very high to relatively low volumes of traffic. Therefore, PCCP should be considered as a potential alternative for all state highway facilities, allowing a comparison of life-cycle economics along with other pertinent or overriding factors to determine the pavement type to be used on any given project.

607.2 Design Procedure for Rigid Pavement

Standard structural section thicknesses are shown in Table 607.2 and should be used in the design of all new PCCP. Structural section element thicknesses vary with Traffic Index (TI) and R-value of the basement soil material. Procedures for developing the TI are described in Topic 603. Determination of the R-Value for the basement soil to be used is discussed in Index 604.2.

Treated permeable bases (ATPB and CTPB) must be given first consideration in PCCP structural section design, as discussed in Index 606.3. The final selection of which of the four bases, shown in Table 607.2, to be used on a given project, depends on specific factors relative to the available materials, terrain, environmental conditions, and past performance of PCCP under similar project or area conditions. Questions on selection of base may be directed to the Pavement Consulting Services Branch in METS.

The standard design directly addresses the all too common drainage related problems discussed in Index 606.3 by the incorporation of either an asphalt or cement treated, free-draining base with an edge drain collector and outlet system or a dense non-erodible base with an edge drain collector and outlet system.

Optional combinations are diagramed in Figures 607.2A and 607.2B. Details of structural section drainage systems are shown in the Standard Plans.

The design procedures preclude the use of PCCP over low R-value materials ($R < 10$) unless the material is treated with an approved stabilizing agent such as lime. PCCP is also precluded for use over expansive basement soil (Plasticity Index > 12) and over areas subject to significant differential settlement or lateral movement.

Table 607.2

PCCP Structural Section Thickness Guidelines (mm)

TI	Basement Soil R-value 10-40[1]					
	PCCP	Treated Permeable Base[3] (ATPB) (CTPB)	Aggregate Base (AB)	Subbase (AS)	Base[2] (LCB,ACB)	Subbase (AS)
6-7	150	105	105	105	105	120
7.5-8	185	105	105	105	105	120
8.5-10	215	105	105	105	105	150
10.5-12	230	105	105	150	120	185
12 +	260	105	105	245	150	215

TI	Basement Soil R-value > 40					
	PCCP	Treated Permeable Base[3] (ATPB) (CTPB)	Aggregate Base (AB)	Subbase (AS)	Base[2] (LCB,ACB)	Subbase (AS)
6-7	150	105	105	--	105	--
7.5-8	185	105	105	--	105	--
8.5-10	215	105	120	--	120	--
10.5-12	230	105	120	--	120	--
12 +	260	105	105	105	150	--

NOTES :

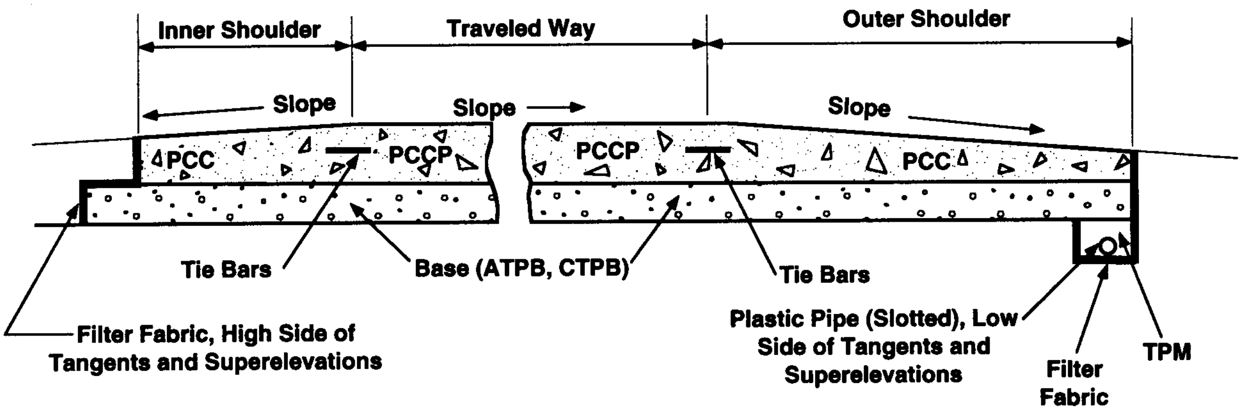
1. With an expansive basement soil (Plasticity Index > 12) and/or basement soil R-value < 10, a flexible structural section (ACP) should be specified unless the R-value of the basement soil is raised above 10 by treatment, to a minimum depth of 200 mm, with an approved stabilizing agent such as lime.
2. CTB with a 30 mm DGAC cap may be used only under special conditions with the approval of OPPD.
3. The standard thickness under PCCP for both ATPB and CTPB is 105 mm which allows the contractor the option to choose the most economical base.

Legend

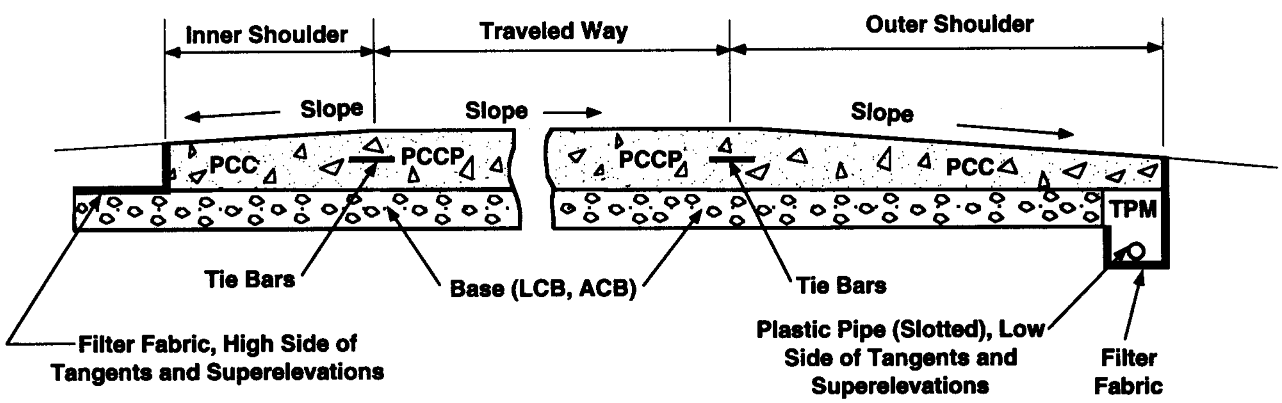
LCB = Lean Concrete Base
ACB = Asphalt Concrete Base
ATPB = Asphalt Treated Permeable Base
CTPB = Cement Treated Permeable Base
AB = Aggregate Base
AS = Aggregate Subbase

Figure 607.2A

Concrete Pavement Details
(Concrete Shoulders)



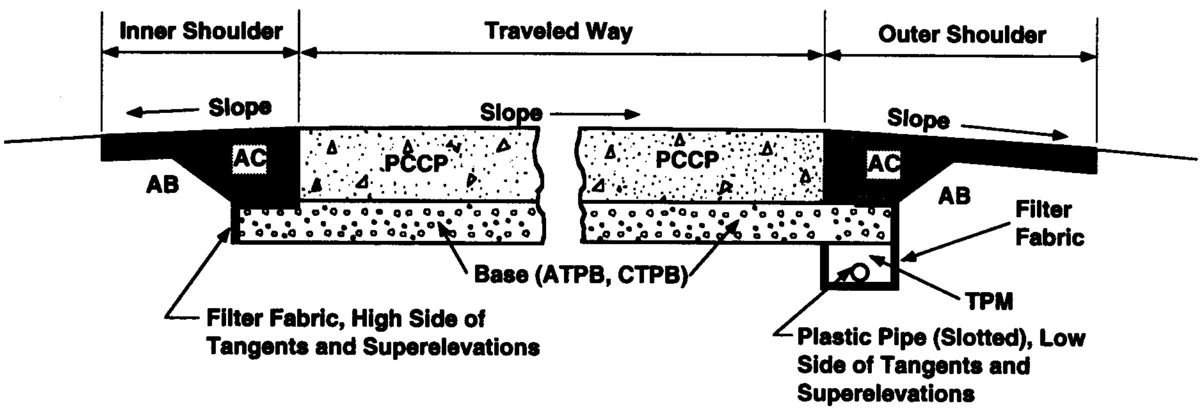
Permeable Base



Dense Base

Figure 607.2B

Concrete Pavement Details (Asphalt Concrete Shoulders)



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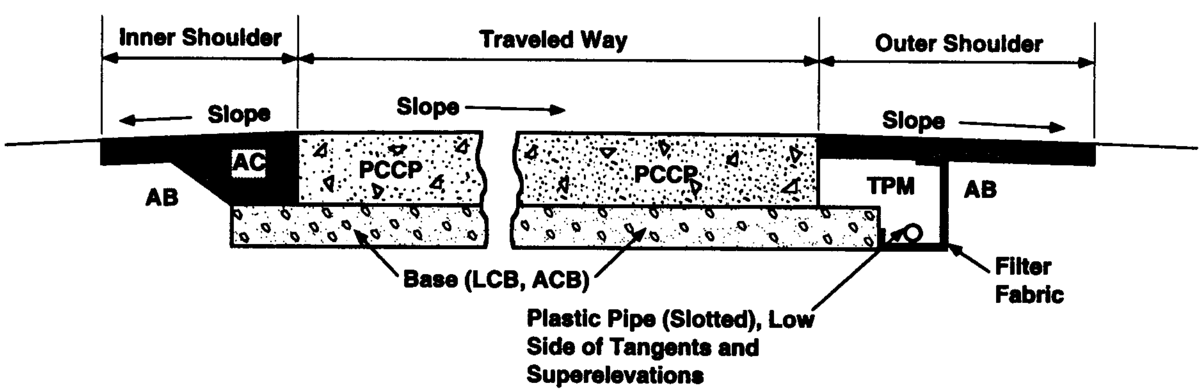


Dense Base

NOTE: PCC shoulders are to be used for all PCCP new construction, however, AC shoulders may be used when justified and approved per Index 602.1(3).

607.3 Structural Section Geometry

On projects with three or more lanes in one direction, the PCCP thickness is varied for the difference in traffic index between the median and outside lanes. Past practice has been to construct steps, in the subbase and base, at the lane line where the PCCP thickness changes. This practice is still satisfactory.

It is also considered acceptable practice to construct a base of uniform thickness and a tapered pavement as shown in Figure 607.3 if the difference in PCCP thickness between the outer lanes and median lane(s) is 30 mm or less. Placing the treated base hinge point 0.6 m away from the lane line minimizes the potential for a "volunteer" longitudinal crack in the base at the lane line. When PCC shoulders are specified, a hinge point may be required at the median edge of the traveled way to maintain a minimum thickness of 120 mm at the edge of the shoulder.

607.4 Portland Cement Concrete Shoulders and Ramps

Tied PCC shoulders are to be used for all PCC pavements. PCC should also be considered for ramps near major commercial or industrial areas, truck terminals, truck weighing and inspection facilities, etc.

(1) *Shoulders.* Special delineation of concrete shoulders may be required to deter the use of the shoulder as a traveled lane. The District Division of Operations should be consulted to determine the potential need for anything more than the standard edge stripe.

On new facilities, if the future conversion of the shoulder to a traffic lane is within the design life of the pavement, the shoulder structural section must be equal to that of the adjacent traveled way and should be 3.6 m wide. The cross slope should also be the same as the traveled way, see Index 302.2(3).

PCC shoulders used with PCC pavement (see Figures 607.2A and 607.3 for details) are to be tied to the adjacent lane with tie bars (0.75 m long deformed #15 bars on 0.75 m centers), see Standard Plan A35A. No more than 15 m width of PCC should be tied together.

(2) *Ramps.* When ramp widening is required on loop ramps to handle truck off-tracking, as covered in Index 504.6, the full structural section should extend to the inner edge of the ramp widening.

Heavy trucks create deterioration by flexure of the pavement. This is compounded on AC ramps by severe damage to the asphalt concrete pavement near the termini of some heavy traffic exit ramps, generally caused by the dissolving action of oil drippings combined with the braking of trucks. Therefore, PCCP should be used at all new AC exit ramp termini where a significant volume of trucks is anticipated.

Because of the relatively high cost of constructing short lengths of PCCP, its use on restoration of existing ramps should be limited to those locations where severe damage has already occurred and maintenance costs plus traffic delay justify complete replacement.

The length of PCC pavement to be placed at the termini will depend on experience in the area, ramp grades, and the length of queues of stopped traffic. A length of 45 m should be considered the minimum. Special care should be taken to assure adequate skid resistance in the braking area, especially where oil drippage is concentrated.

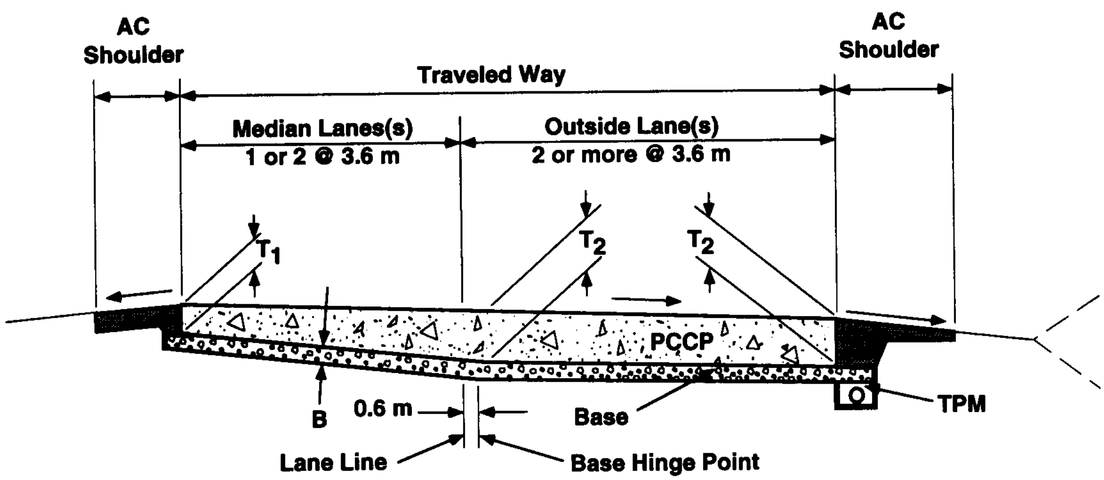
The PCC pavement for the termini of AC exit ramps must be a minimum of 260 mm thick over a base thickness of 150 mm. Special attention should be given to base type selection to assure continuity and adequacy of drainage.

When the entire new ramp is concrete, consider utilizing the same base and thickness as that to be used under the traveled way, especially when concrete shoulders are utilized. If the base is TPB under the traveled way and shoulder, TPB should be utilized in the ramp area whenever feasible.

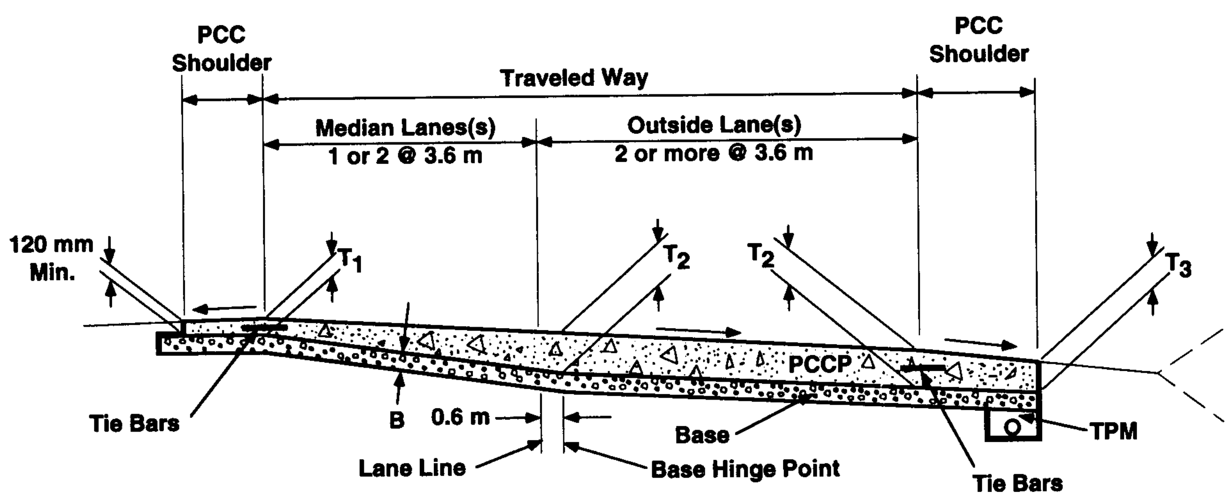
For ramp reconstruction, some use of the existing base and subbase layers should be considered. In some situations, however, underground water from landscape irrigation or other sources may tend to saturate the existing slow-draining layers, thereby creating the potential for pumping

Figure 607.3

Concrete Pavement Details
Tapered Cross Section For 3 or More Lanes One Direction



ASPHALT CONCRETE SHOULDERS



CONCRETE SHOULDERS

Legend

T1 = PCC Thickness For Median Lane TI.
T2 = PCC Thickness For Outside Lane TI.
T3 = T2 If Shoulder May Be Converted To a Traffic Lane: Otherwise T3 = 150 mm Minimum.
B = Constant Base Thickness For Outside Lane TI For The Entire Width.

and pavement damage. In this case the design should provide for removal of such water by a TPB drainage layer when reconstruction is required or at least by providing a longitudinal edge drain system, whenever feasible.

607.5 Asphalt Concrete Shoulders

AC shoulders should not be used adjacent to new PCC pavements, however, in those instances where AC shoulders are used with concrete pavement they should be designed in accordance with Index 608.5 and the details shown in Figure 607.2B.

607.6 Pavement Joints

(1) *Joint types.* Joints used in portland cement concrete pavement are longitudinal and transverse contact joints, longitudinal and transverse weakened plane joints, and transverse pressure relief joints. Contact joints are formed by placing concrete on one side of a planned joint and allowing it to set before the concrete is placed on the other side of the joint. Transverse weakened plane joints are constructed by partial depth sawing of the concrete, or by inserting a plastic strip (if specified as an option) and thereby inducing a tensile shrinkage crack to the bottom of the slab. All longitudinal weakened plane joints must be constructed by partial depth sawing to avoid problems encountered in the past when utilizing the plastic insert method.

Transverse weakened plane joints are constructed, as specified in the Standard Specifications and as shown on Standard Plan A35A, using the repetitive joint spacing of 3.6 m, 4.6 m, 4.0 m, and 4.3 m. These joints are skewed counterclockwise 1 in 6. Longitudinal joints (except contact joints) are constructed, by sawing, at all lane lines, including the edge of traveled way when concrete shoulders are specified. At present, Caltrans does not use dowels in PCCP transverse joints except on an experimental basis. However, Caltrans does use tie bars on all longitudinal joints as shown in the Standard Plans. No more than 15 m width of PCC should be tied together.

When a single lane is being placed to widen existing concrete pavement, weakened plane joints may be diagonal or normal to the edge of pavement to match existing joint spacing and orientation.

(2) *Joint Sealing.* Caltrans has rarely used joint seals in the past. However, with recent developments in joint design and joint materials, it appears that sealing of joints has a significant potential for cost effectiveness provided careful attention is given to selection of materials as well as construction of the sealed joints.

Entrance of fines, or incompressibles, into and through pavement joints may lead to, or contribute to, step faulting, joint spalling, excessive pressure against bridge abutments, and pavement blowups. This is especially critical on high elevation routes where sanding is used during icing conditions, and in blow-sand areas where fine sand is deposited on the roadbed. The problems of step faulting and joint spalling are also apparent, in varying degrees, under a wide range of conditions throughout the state. The entry of surface water into pavement joints has also played a major role in accelerating pavement deterioration.

Because of the factors discussed above and to minimize the spalling of transverse joints and the need for costly and disruptive repairs on heavily traveled urban freeways, the sealing of all joints to deter the entry of fine or incompressible materials and water is to be specified on all new concrete pavements. However, when one or more lanes are added for widening, the joints should not be sealed unless the transverse and longitudinal joints (and cracks) in adjacent lanes are also sealed.

When joints are to be sealed, the joint dimensions (shape factor) and preparation are critical to good performance and must be constructed per the Standard Specifications and Standard Plans. Silicone joint sealant is to be used for all transverse and longitudinal joints. Generally, the joint is prepared by sawing, cleaning, and placement of a backer rod. The PE can contact the Pavement Consulting Services Branch in METS for technical guidance on sealing materials and joint design.

(3) *Other Joint Considerations.* Transverse pressure relief joints may be required in the construction of PCCP to relieve longitudinal forces. These forces may be induced by thermal expansion alone on long flat grades or by a combination of thermal and gravitational forces acting over a period of time on relatively steep grades. Unsealed transverse joints that become filled with "incompressible" materials compound this phenomenon; ultimately there is spalling of concrete at the joints and the transmission of expansive forces from slab-to-slab in the concrete pavement which may create blow-ups.

When required, pressure relief joints should be constructed in conjunction with pavement end anchors (see Figure 606.3 and Standard Plan A35A). Since pavement blow-ups are relatively uncommon on State highways in California, the need for pressure relief joints is primarily near the end of structures to prevent the transmission of expansive forces from the concrete pavement to the structure. This is most likely to develop where there are sustained high temperatures (over 32° C) in combination with long, flat or steep down grades (4% or greater) leading to a structure. When specified near a structure, the pressure relief joint should be located at least 30 m away from the paving notch and a maximum of 30 m from the end of the structure approach slab or the sleeper slab.

The need to specify the sealing of joints and the potential need for installation of pressure relief joints should be discussed in the Geotechnical Design Report or Materials Report, as appropriate. This report should also discuss any historical problems observed in the performance of PCCP constructed with aggregates found in the proximity of the project and exposed to similar physical and environmental conditions.

Details of concrete pavement expansion and contraction joints, end anchors, pressure relief joints, and structure approach slabs are shown in the Standard Plans or DOS Standard Details. Joint construction methods and details and the materials used for sealing joints are covered in the Standard Special Provisions and Standard Specifications. Unique project features should be covered in the Plans and Special Provisions.

607.7 Concrete Pavement Texturing

Concrete pavements are textured with striations running in the longitudinal direction. Initial texturing is performed with a burlap drag or a broom. This is followed by the application of spring steel tine device which will produce grooves, about 5 mm deep on 19 mm centers, parallel with the centerline. This type of texturing, which is specified in the Standard Specifications, has been found to provide a durable skid resistant riding surface. Under average exposure conditions the surface texture is expected to last throughout the 20-year pavement design period with a minimum of maintenance.

Topic 608 - Asphalt Concrete Pavement Structural Section Design

608.1 Introduction

Flexible pavement structural sections usually are constructed of an asphalt concrete surface layer that is placed over a treated or untreated base layer and an untreated subbase layer. The two primary alternates (ACP and PCCP) should be considered in the design of a new highway or freeway or widening project.

When compared to rigid pavement (PCCP), asphalt concrete pavement (ACP) has the advantage of being able to adjust more readily to differential settlement that is likely to occur where the roadway is constructed on relatively flexible or variable quality basement soil. In addition it can be more readily repaired or recycled.

The primary disadvantages of ACP are that it generally requires a higher level of maintenance than PCCP and may require significant rehabilitation measures (overlay or surface treatment) due to age hardening and loss of fatigue resistance after initial construction.

608.2 Asphalt Concrete Pavement Materials Types

The asphalt concrete pavement materials listed in Table 608.2 are alternatives that may be

Table 608.2

Asphalt Concrete Types

Type	Abbreviation	Gravel Factor, G_f
Dense Graded Asphalt Concrete (Types A and B)	DGAC	See Table 608.4
Open Graded Asphalt Concrete	OGAC	1.4
Rubberized Asphalt Concrete	RAC	*
Sulfur Extended Asphalt Concrete	SEAC	*

* G_f has not been determined for these experimental materials. The G_f will be provided by METS.

considered in design of the pavement structural section. Following is a brief discussion of each with some guidelines on the conditions where the use of each type may be appropriate.

(1) *Dense Graded Asphalt Concrete (DGAC).* DGAC consists of a mixture of bituminous material (paving asphalt) and a close graded aggregate ranging from coarse to very fine particles. DGAC is designated as Type A or Type B, depending on the specified aggregate quality and mix design criteria appropriate for the job conditions. Special attention is given to mix design and compaction in the construction phase to minimize voids and to assure stability, durability, and maximum service life.

(2) *Open Graded Asphalt Concrete (OGAC).* OGAC is a surface course used primarily on DGAC. It has occasionally been used on portland cement concrete pavements. The primary benefit of using OGAC is the reduction of wet pavement accidents by improving wet weather skid resistance, minimizing hydroplaning, reducing water splash and spray, and reducing nighttime wet pavement glare. Secondary benefits include better wet-night visibility of traffic stripes and markers, better wet weather (day and night) delineation between the traveled way and DGAC shoulders, and increased safety through reduced driver stress during rainstorms. OGAC surfacing is also known as an "open graded friction course".

(a) New Construction Projects. The surface course of OGAC should be considered for new DGAC pavement projects in areas where one or more of the following conditions apply:

- Hydroplaning is known to be a problem.
- High rainfall intensities are common.
- The cross slope is less than 2% on facilities with 3 or more lanes in one direction.
- Moderate to high rainfall intensities are common, especially when combined with high traffic volumes.

(b) Rehabilitation Projects. OGAC should be considered for use on AC pavement rehabilitation projects where one or more of the following conditions apply:

- There is a high wet weather accident frequency.
- Hydroplaning is known to be a problem.
- Surface attrition or raveling is occurring.
- The cross slope is less than 2% on facilities with 3 or more lanes in one direction.
- Moderate to high rainfall intensities are common, especially when combined with high traffic volumes.

(c) Cautions. OGAC should not be used:

- As a routine surface seal. See Division of Maintenance Memorandum, “Roadway Maintenance Surface Treatment Strategies (Recommended Guidelines)”, dated January 3, 1994 or contact the Pavement Consulting Services Branch in METS for details.

- In snow areas generally above 900 m elevation (where there is a potential for exposure to tire chains and studded tires).

- In parking areas.

- In areas where tracking of mud from unsurfaced side roads is common and frequent.

- When a life-cycle cost comparison shows significant cost savings and/or other benefits utilizing alternatives (such as a chip seal in a low traffic volume area).

- At intersections where dripping of oil or fuel from slow or stopped vehicles and short radius turning actions could cause the surface to deteriorate rapidly.

OGAC is generally used on the traveled way and "feathered" out to the approximate thickness of the maximum size aggregate within 0.3 m of the outside edge of pavement (EP). It may, however, be used on shoulders when justified in the Project Report (PR) or Project Scope Summary Report (PSSR), and primarily based on safety and/or cost savings.

OGAC mixtures placed in a thickness of 18 mm or less should utilize the 9.5 mm maximum aggregate size gradation. When the thickness exceeds 18 mm, the 12.5 mm gradation should be used. When OGAC is used on pavement rehabilitation as the surface course (as part of an overlay to retard reflection cracking) it may be substituted directly for up to 30 mm maximum of the recommended overlay thickness. When used as part of the structural section of new construction, a gravel factor (G_f) of 1.4 is assigned to the OGAC element.

In summary, the use of OGAC is encouraged where appropriate under the above guidelines. It must, however, be clearly justified in the PSSR for rehabilitation and PR for new construction. For new construction or major reconstruction, justification must be included in the structural section submittal (See Index 602.1) and referenced in the project approval document, typically the PR.

(3) *Rubberized Asphalt Concrete (RAC)*. Rubberized asphalt is formulated by mixing granulated rubber with hot asphalt to form a tough and elastic binder with less susceptibility to temperature changes. The rubberized asphalt is substituted for the regular asphalt as the binder for AC mix. The cost of RAC is significantly higher than that of conventional DGAC but RAC can be placed routinely in overlays at a reduced thickness using Caltrans Guidelines (Contact METS Pavement Consulting Services Branch for details.).

Field trials of RAC constructed on construction-evaluated projects by Caltrans appear to be performing well. RAC was specified on those projects primarily to resist tire chain wear, to resist thermal stresses created by wide temperature variations, and to retard reflection cracking. Today RAC is generally specified to retard reflection cracking, resist thermal stresses created by wide temperature variations and add flexibility to a structural overlay. Dense graded RAC is specified to resist tire chain wear.

Rubberized asphalt is also commonly used as a binder for surface and interlayer chip seals and as a pavement joint and crack sealant.

RAC is only used on an experimental basis for new construction, see Index 602.1(3).

(4) *Sulphur Extended Asphalt Concrete (SEAC)*. Sulphur extended asphalt concrete is an aggregate mixture that is bound together with a mixture of asphalt and sulphur. Its use to date has been confined to experimental projects. The use of SEAC is dependent on the availability of sulphur, a by-product of some manufacturing processes, at a price that would make it more economical than asphalt.

608.3 Asphalt Surface Treatments

There are a number of asphalt surface treatments that may be considered in the design of the structural section, see Table 608.3. They generally do not contribute to the strength of the structural section but fulfill other purposes as discussed.

Table 608.3

Asphalt Surface Treatments

Type	Abbreviation	General Purpose
Penetration Treatment	PT	Seal and Stabilize
Prime Coat	PC	Bond AC to Base
Paint Binder	PB	Bond New AC to Existing Surfaces and Contact Joints

(1) *Penetration Treatment (PT).* Penetration treatment consists of an application of liquid asphalt to an underlying compacted roadbed material. It is used principally as a surface stabilizing agent on light traffic detours, medians, and parking areas, and as a dust palliative.

(2) *Prime Coat (PC).* A prime coat is an application of liquid asphalt used to prepare an untreated base for an AC surface course or TPB. The prime coat penetrates the compacted base to the extent that it fills surface voids, hardens the top to prevent erosion, and helps bind it to the AC surfacing or TPB layer. A contract item for sand cover should be provided where any traffic will have to use the primed area prior to paving.

The purpose of a prime coat is generally limited to:

- Minimizing the likelihood of raveling or displacement of the underlying material when traffic will be routed through the work on the aggregate base (AB),
- Protecting the aggregate base (AB) surface by preventing erosion of fines at the ATPB/AB or CTPB/AB interface, or
- Protecting the base if extended inclement weather and/or extended delays in placing the surfacing are anticipated, or
- Protecting thin asphalt concrete (AC) layers of 75 mm or less from the loss of adherence to the AB due to traffic load-induced horizontal shearing forces at the AC/AB interface.

A prime coat may be warranted, depending on other factors unique to a given project, even though the first conditions shown above do not exist and the AC thickness is greater than 75 mm and less than 150 mm. No prime coat should be applied when the AC thickness is 150 mm or greater unless the first two conditions shown above exist.

(3) *Paint Binder (PB).* A paint binder consists of an asphaltic emulsion which is applied to all vertical surfaces of pavement, curbs, gutters, and construction joints against which asphaltic surfacing is to be placed. It generally is also applied to existing asphalt surfaces before placing a layer of open graded or dense graded asphalt concrete.

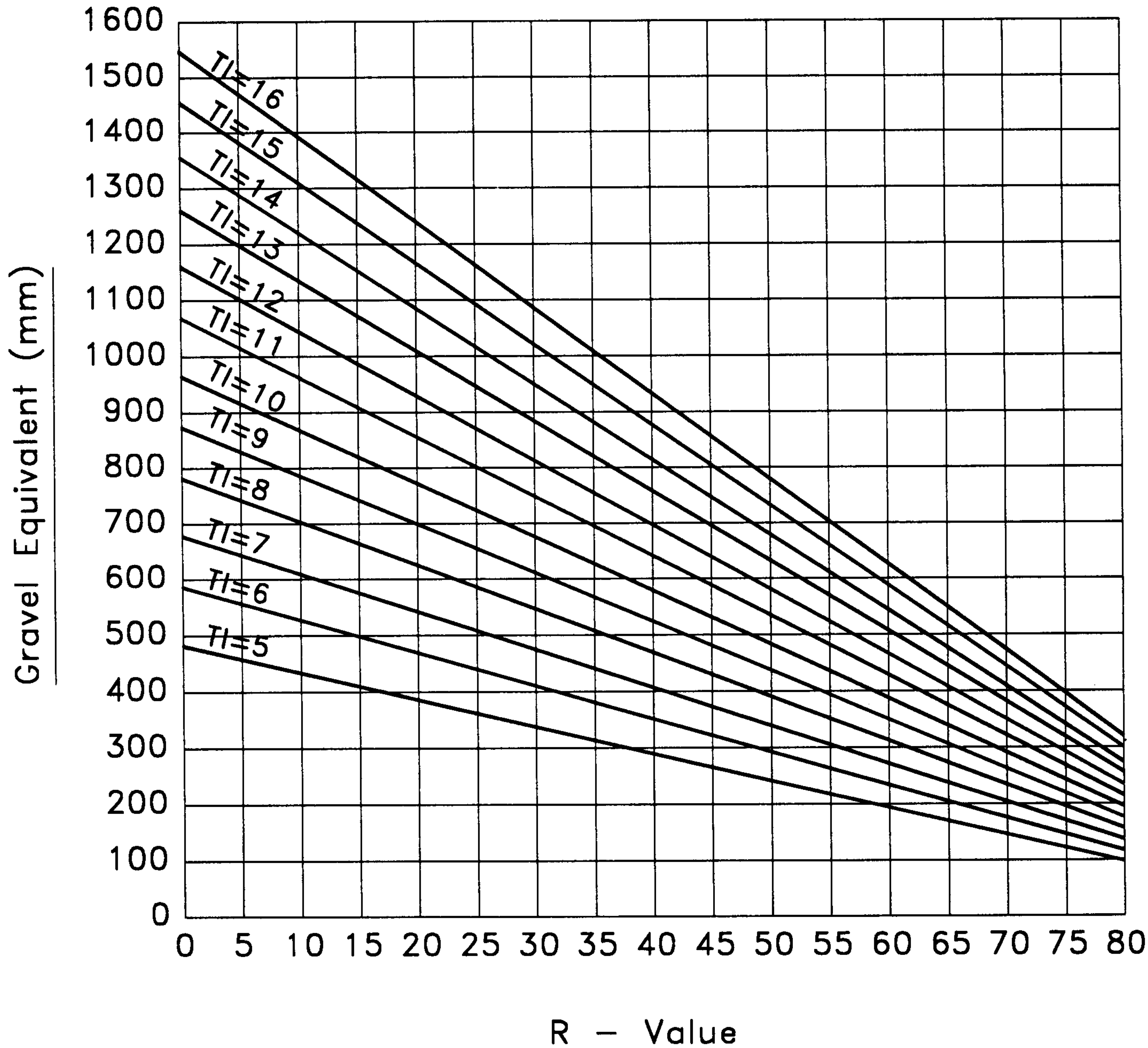
608.4 Design Procedure for Flexible Pavement

Design of the flexible pavement structural section is based on a relationship between the "gravel equivalent" (GE) of the structural section materials, the Traffic Index (TI), and the R-value (R) of the underlying material. This relationship was developed by METS through research and field experimentation and is represented by the equation GE = 0.975 (TI)(100-R). This is illustrated graphically in Figure 608.4, which is used primarily to check computed values of the required GE for the total structural section and for the pavement, base, and subbase layers.

The GE requirement for the structural section can be provided by a wide variety of pavement, base, and subbase materials in various combinations of layer thicknesses that are designed primarily to spread and transmit the live load to the underlying roadbed. Base and subbase types are listed in Table 605.1 and discussed in Topic 605. Asphalt concrete pavement types are listed in Table 608.2 and discussed in Index 608.2. The type of materials that might be used in the structural section is investigated thoroughly by the district materials staff and recommendations are made in the

Figure 608.4

Flexible Pavement Structural Section Design



Legend

GE = Gravel Equivalent = 0.975 (TI)(100-R)
TI = Traffic Index
R = Resistance Value or R-Value

Geotechnical Design Report or Materials Report based on availability and adequacy to meet the project requirements. The pavement type selection, which has a direct bearing on the base and subbase materials to be used, is discussed in Topics 602 and 609. As indicated in Topic 606, positive rapid drainage is very important. Any omission of the treated permeable base layers must be supported by appropriate written justification, see Index 602.1.

The projected truck traffic data and ultimately the TI for structural section design are developed as described in Topic 603. The R-value of the basement soil is provided in the Geotechnical Design Report or Materials Report. In some cases there may be significant variations in this R-value, particularly for projects that are several kilometers or more in length. More than one R-value may be designated, for economic reasons, to vary the structural section to fit local conditions on selected stretches within a project.

On projects utilizing ACP, with three or more lanes in one direction, separate lane designs are based on the different TI's for the median and outside lanes. Determination of the ESAL's and conversion to lane TI's is illustrated in Tables 603.4A and 603.4B. This results in variable structural section layer thicknesses, and in steps in the structural section layers at the lane lines where the thickness changes.

(1) *Basic Design Data.* The basic design data required for flexible pavement design includes:

   (a) R-values from the Geotechnical Design Report or Materials Report, including that for basement soils, and subbase. When the basement soil is expansive, the R-value for that soil is the "expansion pressure R-value" (which will result in a thicker subbase but will not affect other layers).

   (b) Number of lanes from the Project Report (or other project approval document).

   (c) Expanded annual average daily truck traffic (AADTT) from the District Division of Planning, for the design period. This information is developed and transformed into the TI, as described in Topic 603, for use in the design of the structural section.

(2) *Structural Section Safety Factors.* Construction tolerances allowed by the contract specifications could result in a structural section that is slightly deficient in thickness. To compensate for this possibility, a safety factor is applied by increasing the design thickness of the pavement. For structural sections that include base and/or subbase layers, a safety factor of 60 mm is added to the required GE of the AC. Since application of the safety factor is not intended to increase the total GE of the structural section, a compensating thickness is subtracted from the GE thickness of the subbase layer. Where there is no subbase, the safety factor is subtracted from the base layer. In no case is the thickness of a layer to be reduced to less than the allowable minimum.

   For structural sections that are essentially full depth AC, a safety factor of 30 mm is added to the required GE of the AC. When determining the appropriate safety factor to be added, ACB and ATPB should be considered as part of the AC layer. Full depth AC sections will therefore exceed the calculated required GE by the safety factor since there are no underlying layers to adjust.

(3) *Basic Rules for Designing Flexible Pavements.* When designing flexible structural sections, the following basic rules will apply:

   (a) The TI is determined to the nearest 0.5.

   (b) The following standard design formula is applied to determine the GE of the cover required over the basement soil and intermediate structural section layers with a known or assumed R-value:

   $$GE = 0.975(TI)(100-R)$$

   where:

   GE = gravel equivalent in mm

   TI = traffic index (See Index 603.4)

   R = R-value of the material to be covered

   (c) The GE to be provided by each material is determined in order by layer, starting with the AC and proceeding downwards.

(d) Safety factors are applied by increasing the GE of the AC by the amount indicated in Index 608.4(2). An equal GE is subtracted from the subbase layer (base layer when there is no subbase).

The safety factor must be included when calculating the required GE of the combined AC and base material. When full depth AC is used, there may not be an underlying layer from which to subtract the safety factor GE. In these cases, a full depth AC section will slightly exceed the required cover.

(e) Base and subbase materials, other than ATPB, should have a minimum thickness of 105 mm. When the calculated thickness of base or subbase material is less than the desired 105 mm minimum thickness, either increase the thickness to the minimum without changing the thicknesses of the overlying layers or eliminate the layer and increase the thickness of the AC or base layer to compensate for the reduction in GE.

(f) Treated permeable bases are placed under flexible pavement in standard thicknesses of 75 mm of ATPB or 105 mm of CTPB, see Index 606.2(3).

(g) The thickness of each material layer is calculated by dividing the GE by the appropriate G_f (From Table 605.1 or 608.4). Note that the G_f of AC is not a constant value. As the TI increases, the G_f decreases. Also, the G_f of the AC gradually increases for any given TI as the total thickness of AC increases above 150 mm. The following equations can be used to calculate the G_f of asphalt concrete, but are only provided here for information:

AC Thickness *(t)* less than or equal to 150 mm:

$$G_f = 5.67/(TI)^{1/2}$$

AC thickness *(t)* greater than 150 mm:

$$G_f = (1.04)(t)^{1/3}/(TI)^{1/2}$$

Table 608.4 should normally be used in lieu of using these equations to determine AC thicknesses. When selecting the design layer thickness, the value is rounded to the nearest 15 mm. A value midway between 15 mm increments is rounded to the next higher value.

(h) The design procedure provides the minimum allowable thickness of AC for the project conditions. This thickness may be increased when appropriate to minimize construction costs, reduce construction time, match layer placement with existing adjacent lanes, reduce the number of layers, etc., provided the minimum GE and construction requirements are satisfied.

(i) The thicknesses of other structural section layers determined by the procedures described below may be adjusted to accommodate construction practice and minimize cost provided the minimum GE and construction requirements are satisfied.

(j) When Lime Treated Subbase (LTS) is used as a subbase it is substituted for all, or part, of the required AS layer. The design thicknesses of the base and AC surfacing layers are determined as though AS is the planned subbase material. The LTS is then substituted for the AS. Since AS has a G_f of 1.0, the actual thickness and the GE are equal. When LTS is substituted for the AS, the actual thickness is determined by dividing the GE by the appropriate G_f based on unconfined compressive strength (see Index 605.9).

(k) Construction convenience and/or materials availability may at times make it advantageous to the contractor to replace the AS layer with additional base. This substitution should be considered when the required thickness of AS is less than 105 mm or when otherwise economically justified.

(4) *Structural Section Design Procedures.* A flexible pavement structural section can consist of various combinations of materials. It is, therefore, necessary to first consider the types of materials available. This information is included in the Geotechnical Design Report or Materials Report.

Table 608.4

Gravel Equivalents of Structural Layers (mm)

Actual Thickness of Layer	ASPHALT CONCRETE (DGAC)											BASE AND SUBBASE					
	Traffic Index (TI)																
	5 & below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	14.5 & up	ACB; LCB	CTPB; CTB (Cl. A)	ATPB	CTB (Cl. B)	AB	AS
	Gravel Factor (G_f)																
	G_f varies with TI[4]											G_f constant					
(mm)	2.54	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.46	1.9	1.7	1.4	1.2	1.1	1.0
30	76	70	64	60	57	54	51	49	47	46	44	--	--	--	--	--	--
45	114	104	96	90	85	81	77	74	71	68	66	--	--	--	--	--	--
60	152	139	128	121	113	107	103	98	94	91	88	--	--	--	--	--	--
75	191	174	161	151	142	134	128	123	118	114	110	--	--	105[2]	--	--	--
90	229	209	193	181	170	161	154	148	141	137	131	--	--	126	--	--	--
105	267	244	225	211	198	188	180	172	165	160	153	200	180[2]	147	126	116	105
120	305	278	257	241	227	215	205	197	188	182	175	228	204	168	144	132	120
135	343	313	289	271	255	242	231	221	212	205	197	257	230	189	162	149	135
150	381	348	321	302	284	269	257	246	236	228	219	285	255	210	180	165	150
165	421	392	362	338	318	301	287	275	264	254	247	314	281	231	198	182	165
180	473	441	407	380	357	338	322	308	296	285	278	342	306	252	216	198	180
195	526	490	453	422	397	377	359	343	329	317	309	371	332	273	234	215	195
210	--	541	500	466	439	416	396	379	363	350	341	399	357	--	252	231	210
225	--	593	548	511	481	456	434	415	399	384	374	428	383	--	270	248	225
240	--	647	597	557	524	497	473	452	434	418	407	456	408	--	288	264	240
255	--	--	647	604	568	538	513	491	471	453	442	485	434	--	306	281	255
270	--	--	698	652	613	581	553	529	508	489	477	513	459	--	324	297	270
285	--	--	--	701	659	625	595	569	546	526	512	542	485	--	342	314	285
300	--	--	--	750	706	669	637	609	585	563	548	570	510	--	360	330	300
315	--	--	--	801	753	714	680	650	624	601	585	599	536	--	378	347	315
330	--	--	--	--	802	759	723	692	664	639	623	--	--	--	--	--	330
345	--	--	--	--	851	806	767	734	705	679	661	--	--	--	--	--	345
360	--	--	--	--	900	853	812	777	746	718	699	--	--	--	--	--	360
375	--	--	--	--	--	901	858	820	787	758	738	--	--	--	--	--	375
390	--	--	--	--	--	949	904	864	830	799	778	--	--	--	--	--	390
405	--	--	--	--	--	998	950	909	873	840	818	--	--	--	--	--	--
420	--	--	--	--	--	--	997	954	916	882	859	--	--	--	--	--	--
435	--	--	--	--	--	--	1045	1000	960	924	900	--	--	--	--	--	--
450	--	--	--	--	--	--	1094	1046	1004	967	942	--	--	--	--	--	--
465	--	--	--	--	--	--	--	1093	1049	1010	984	--	--	--	--	--	--
480	--	--	--	--	--	--	--	1140	1094	1054	1026	--	--	--	--	--	--
495	--	--	--	--	--	--	--	1188	1140	1098	1069	--	--	--	--	--	--
510	--	--	--	--	--	--	--	--	1187	1143	1113	--	--	--	--	--	--
525	--	--	--	--	--	--	--	--	1233	1188	1156	--	--	--	--	--	--
540	--	--	--	--	--	--	--	--	1280	1233	1201	--	--	--	--	--	--
555	--	--	--	--	--	--	--	--	--	1279	1245	--	--	--	--	--	--
570	--	--	--	--	--	--	--	--	--	1325	1290	--	--	--	--	--	--
585	--	--	--	--	--	--	--	--	--	1372	1336	--	--	--	--	--	--
600	--	--	--	--	--	--	--	--	--	--	1382	--	--	--	--	--	--

Notes:
1. See Tables 605.1 and 608.2 for subbase, base and asphalt concrete types, abbreviations, and gravel factors (G_f).
2. Standard layer thicknesses of 75 mm and 105 mm have been adopted respectively for ATPB and CTPB. These in turn correspond respectively to GEs of 105 mm and 180 mm. As discussed in Index 606.2(3), a thicker TPB drainage layer may be considered only under a unique combination of conditions.
3. OGAC may be substituted for up to 30 mm of DGAC, as a surface layer, when warranted by conditions discussed under Index 608.2(2), the difference in G_f not withstanding.
4. DGAC G_f also increases as the thickness increases, if the thickness is greater than 150mm - See Index 608.4(3)(g).

The procedures to be followed when using treated bases and/or subbases (CTB-A, LCB, LTS) are somewhat different from those used when only untreated bases and subbases (AB, AS) are used. These procedures are discussed separately in the following paragraphs. A computer program, based on the procedures presented in this manual, is available from the METS Pavement Consulting Services Branch or the District Materials Engineer, for use in the design of flexible pavement structural sections. The use of this program enables the designer to compare numerous combinations of materials in seeking the most economical structural section.

(a) The following rules will apply in addition to the basic rules listed above when an untreated base or CTB-B is utilized.

- The GE determined by the formula is the total required, without a safety factor, for the layer or layers above the material whose R-value is used in the computation.
- When a treated permeable base is used, the required GE of the AC is determined by adding the safety factor to 40% of the GE required over the subbase (or basement soil when it is of such quality that AS is not required). The treated permeable base thickness will be either 75 mm (ATPB) or 105 mm (CTPB). The thickness of the untreated base or CTB-B is determined using the standard design formula.

(b) When using a treated base which is not subject to the R-value test, the following rules will apply in addition to the basic rules listed above.

- The initial GE of the AC is 0.4 of the total GE required over AS. In cases where the basement soil is of such quality that AS is not necessary, the R-value of the basement soil is used. If additional base is to be placed in lieu of the AS layer, use a R-value of 50 for this calculation.
- The required safety factor is added to the initial GE of the AC to determine the minimum GE of the AC.
- ACB is considered part of the AC pavement layer.

(5) *Design Example 1 - Undrained Structural Sections Designed per R-values of Underlying Layers (AC/AB/AS or AC/CTB-B/AS).*

(a) Determine the required structural section GE using the standard design formula and the R-value of the basement soil. For this example, assume an 8-lane divided freeway will be constructed over a basement soil with a R-value of 10. Using the TI example cited in Section 603.4, TI's of 12.5 and 11.0 are assigned, respectively, to the outside lanes and median lanes. Thus, the total required GE is:

Outside lanes: 0.975(12.5)(100-10) = 1097

Inside lanes: 0.975 (11.0)(100-10) = 965

(b) Determine the required GE of the AC layer using the standard design formula. In this case, R is the R-value of the AB layer.

Outside lanes: 0.975 (12.5)(100-78) = 268

Inside lanes: 0.975(11.0)(100-78) = 236

(c) Add the required 60 mm safety factor to these values to determine the total GE of AC:

Outside lanes (OL): 268 + 60 = 328 mm

Inside lanes (IL): 236 + 60 = 296 mm

(d) Use Table 608.4 to determine the actual thickness required:

OL: 195 mm (GE is 328)

IL: 165 mm (GE is 296)

(e) Determine the GE of the actual thicknesses from Table 608.4:

OL: 329

IL: 287

(f) Determine the required GE of the combined AC and AB layers using the standard design formula. In this case, R is the R-value of the AS layer. For this example, assume a Class 2 AS which has a specified minimum R-value of 50.

OL: GE = 0.975(12.5)(100-50) = 609

IL: GE = 0.975(11.0)(100-50) = 536

(g) Add the required 60 mm safety factor to these values to determine the required GE of the combined AC and AB.

OL: 609 + 60 = 669

IL: 536 + 60 = 596

(h) Subtract the adjusted GE of the AC (Step e) from the required combined GE of the AC and AB to determine the required GE of the AB.

OL: 669 - 329 = 340

IL: 596 - 287 = 309

(i) Use Table 608.4 to determine the actual thickness required for the AB.

OL: 315 mm (GE is 347)

IL: 285 mm (GE is 314)

Note

If CTB-B is used in lieu of AB, use Table 608.4 to determine actual thicknesses:

OL: 285 mm (GE is 342)

IL: 255 mm (GE is 306)

****

(j) Subtract the adjusted GE of the AC and AB layers from the required GE of the total structural section (Step a) to determine the GE of the AS:

OL: 1097 - 329(AC) - 347(AB) = 421
(Rounded to 420)

IL: 965 -287(AC) - 314(AB) = 364
(Rounded to 360)

Note

If CTB-B is used in lieu of AB, the GE of the AS will be:

OL: 1097 - 329(AC) - 342(CTB-B) = 426
(Rounded to 420)

IL: 965 - 287(AC) - 306(CTB-B) = 372
(Rounded to 375)

****

Since AS has a G_f of 1.0, the actual thickness and the GE are equal.

(k) The structural section layer thicknesses for the above example are:

OL: 195 mm AC, 315 mm AB, 420 mm AS

Note

If CTB-B is used:

195 mm AC, 285 mm CTB-B, 420 mm AS

****

IL: 165 mm AC, 285 mm AB, 360 mm AS

Note

If CTB-B is used:

165 mm AC, 255 mm CTB-B, 375 mm AS

****

(6) Design Example 2 - Undrained Structural Sections with Materials not Subject to R-value Tests (AC/CTB-A/AS).

(a) Determine the total required structural section GE as described in *(5)(a)* above.

(b) Determine the required GE of the combined AC and CTB using the standard design formula and the R-value of the AS. In cases where the basement soil is of such quality that AS is not necessary, the R-value of the basement soil is used. For this example assume a Class 2 AS with a specified R-value of 50.

Note: When AS is to be replaced with additional base material, use R-value 50 in this calculation.

OL: GE = 0.975(12.5)(100-50) = 609

IL: GE = 0.975(11.0)(100-50) = 536

(c) Determine the required GE of the AC layer by multiplying the required GE of the combined AC and CTB layers by 0.4 and adding the safety factor.

OL: GE(AC) = (609 x 0.4) + 60 = 304

IL: GE(AC) = (536 x 0.4) + 60 = 274

(d) Determine the actual thickness of AC required from Table 608.4.

OL: 180 mm (GE is 296)

IL: 165 mm (GE is 287)

(e) Add the safety factor to the GE of the combined AC and CTB layers.

OL: 609 + 60 = 669

IL: 536 + 60 = 596

(f) Subtract the adjusted GE of AC (Step e) from the required GE of the combined AC and CTB to determine the required GE of the CTB.

OL: 669 - 296 = 373

IL: 596 -287 = 309

(g) Determine the actual thickness required for the CTB from Table 608.4.

OL: 225 mm (GE is 383)

IL: 180 mm (GE is 306)

(h) Additional material needed to satisfy the total GE required over the basement soil is made up with AS.

OL: 1097 - 296(AC) - 383(CTB) = 418 (Rounded to 420)

IL: 965 - 287(AC) - 306(CTB) = 372 (Rounded to 375)

(i) The structural section layer thicknesses for the above example are:

OL: 180 mm AC, 225 mm CTB-A, 420 mm AS

IL: 165 mm AC, 180 mm CTB-A, 375 mm AS

(7) *Design Example 3 - Drained Structural Sections Which Include Treated Permeable Bases*.

Note: The efficiency of the drainage layer can be affected by a lack of continuity in the treated permeable base across the width of the traveled way. To help assure adequate drainage on a multilane facility, the AC pavement and the treated permeable base layers should not be stepped to accommodate differences in TIs of adjacent lanes. The resulting overdesign of the AC pavement in the median lanes can be compensated for by reducing the base and/or subbase layer as appropriate to satisfy the GE requirement over the basement soil.

(a) Determine the total required structural section GE as described in *(5)(a)* above.

(b) Determine the required GE of the combined AC, treated permeable base and base using the standard design formula and the R-value of the AS. In this example, Class 2 AS with a specified R-value of 50 is assumed.

Note: When AS is to be replaced with additional base material, use R-value of 50 in this calculation.

OL: GE = 0.975(12.5)(100-50) = 609

IL: GE = 0.975(11.0)(100-50) = 536

(c) Determine the required GE of the AC layer by multiplying the required GE of the combined AC, treated permeable base and base layers by 0.4 and adding the safety factor. On multiple lane roadways the AC thickness is constant for all lanes and is based on the TI of the outside lanes.

All lanes: GE = (609 x 0.4) + 60 = 304

(d) Determine the actual thickness of AC required from Table 608.4 using the outside lane TI (12.5).

All lanes: 180 mm

(e) Determine the GE of the actual thickness from Table 608.4.

OL: 296 (TI = 12.5)

IL: 322 (TI = 11.0)

(f) Add the GE of the treated permeable base layer to the GE of the AC. (105 for 75 mm of ATPB or 180 for 105 mm of CTPB.) ATPB is used in this example.

OL: 296 + 105 = 401

IL: 322 + 105 = 427

(g) Determine the required GE of the base layer by adding the 60 mm safety factor to the GE required over the AS and then subtracting the GE of the combined AC and treated permeable base layers.

OL: GE = 609 + 60 - 401 = 268

IL: GE = 536 + 60 - 427 = 169

(h) Determine the actual thickness of base required from Table 608.4. AB is used in this example.

OL: 240 mm (GE is 264)

IL: 150 mm (GE is165)

(i) Determine the required GE thickness of the AS by subtracting the GE thickness of the combined AC, permeable base, and base layers from the total GE required for the structural section.

OL: 1097 -296(AC) -105(ATPB) -264(AB) = 432 (Rounded to 435)

IL: 965 -322(AC) -105(ATPB) -165(AB) = 373 (Rounded to 375)

(j) The structural section layer thicknesses for the above example are:

OL: 180 mm AC, 75 mm ATPB, 240 mm AB, 435 mm AS

IL: 180 mm AC, 75 mm ATPB, 150 mm AB, 375 mm AS

(8) Design Example 4 - Structural Sections Which Include AC Base.

Asphalt concrete base (ACB) is a dense grade AC material and differs from other AC in that it includes aggregates with a larger nominal size. ACB can be substituted for other AC types in the structural section on an equal basis except that it is not to be used as the surface course. Thus, in the preceding example, the structural section AC thickness would be 45 mm for OL and IL, 135 mm for ACB, etc., if ACB were used.

(9) Full-Depth Asphalt Concrete Structural Section Design. In some instances, it may be desirable to reduce the total thickness of the structural section by placing full depth AC. This can be done using the standard design procedures to calculate the total required GE, including the safety factor of 30 mm, and using Table 608.4 to determine the actual thickness of AC required. In cases where a working table is required, the GE of the working table is subtracted from the total GE required. Drainage layers may be placed below or at an appropriate level within the full depth AC. When the drainage layer is placed between layers of AC, the G_f of the AC is determined based on the total thickness of the AC.

Design Example 5:

An additional lane is to be added adjacent to an existing structural section which has a total thickness of 830 mm consisting of 180 mm AC, 75 mm ATPB, 150 mm CTB, and 425 mm AS. The new lane has a projected TI of 12.5 and will be constructed over a basement soil with a R-value of 10. Full depth AC provides a viable alternative since it will reduce the number of construction layers and the time required to complete the project. The required GE is 1097 mm and a safety factor of 30 mm is added to bring the total required GE to 1127 mm. From Table 608.4 the full depth AC thickness is 495 mm above the basement soil. When a 105 mm working table of AS is placed below the AC the required GE for the AC is reduced to 1022.

When a drainage layer is included, the GE of the AC is further reduced by an amount equal to the GE of the drainage layer. In this example, assume a 75 mm layer of ATPB with a GE of 105. Thus, the GE and thickness of the AC are reduced to 917 and 420 mm respectively.

To assure continuity of the drainage layer between the existing and new pavements the ATPB should be placed at the same level as the ATPB in the existing lane. In this example, the ATPB would be placed beneath the top 180 mm of AC. Thus, the structural section for the additional lane would be 180 mm AC, 75 mm ATPB, 240 mm AC, and 105 mm AS.

(10) Alternate Designs. The design thicknesses determined by the procedures described above are not intended to prohibit other combinations and thicknesses of materials. Adjustments to the thicknesses of the various materials other than ATPB and CTPB may be made to accommodate construction restrictions or practices, and minimize costs: provided the minimum GE requirements, including safety factors, of the basement soil and each layer in the structural section are satisfied.

At times, experimental designs and/or alternative materials are proposed. These should be designed, constructed and evaluated in cooperation with METS.

608.5 Shoulder Structural Section Design

The structural section design of outside shoulders is based on the same method described for the traveled way in Index 608.4.

The design is based on 2% of the projected ESAL's in the adjacent lane, however, a TI less than 5.0 should not be used.

On new facilities, if the future conversion of the shoulder to a traffic lane is within the design life of the pavement, the shoulder should be 3.6 m wide and the structural section must be equal to that of the adjacent traveled way.

Converting shoulders to a portion of a traffic lane should only be undertaken when it is the last available means to provide increased capacity. The preferred solution is permanent conventional widening in accordance with design standards.

When a decision has been made to convert an existing shoulder to a portion of a traffic lane, a deflection study must be made to determine the structural adequacy of the in-place material. The condition of the existing shoulder must also be evaluated for undulating grade, rolled-up AC at the PCC edge, surface cracking, raveling, etc.

The converted facility must provide a roadway that is structurally adequate for the next ten (10) years. This is to eliminate or minimize the likelihood of excessive maintenance or rehabilitation being required in a relatively short period of time because of inadequate structural strength and deterioration of the existing AC that has become brittle with age which will result in poor ride quality.

In an area where there are sustained steep grades (over 4%) without a truck climbing lane, the potential for slow moving trucks encroaching on the shoulder should be considered. If the assumed encroachment exceeds 2% of the ESAL's, the shoulder structural section should be designed accordingly.

Since normally there is no break in the grading plane under the pavement shoulder contact joint, the total GE for the shoulder section is usually more than required because of the excess base thickness. The structural section can be designed with or without an AS layer, depending on the comparative initial costs.

Median shoulders on divided highways are to be paved with a uniform AC thickness of 60 mm over AB without design calculations, unless potential use of the median to carry traffic dictates otherwise.

Medians 4.2 m or less wide on 4-lane undivided cross sections should be paved with a uniform AC thickness equal to the structural section of the traveled way.

608.6 Ramp Structural Section Design

The structural section design of AC ramps is based on the same method used for the traveled way, as shown in Index 608.4. Refer to Index 603.3(3) for determination of design traffic for ramps.

Provisions of positive, rapid drainage of the structural section is very important, as stated in Topic 606, on ramps as well as main lanes. However, including drainage systems in ramp structural sections can sometimes create drainage problems such as accumulation of water in the subgrade of descending ramps approaching local street intersections in flat terrain. Such situations, where there may be no cost effective way to provide positive drainage outlets, call for careful evaluation of local conditions and judgement in determining whether a drainage system should be included in each AC ramp structural section.

Ramp shoulder structural sections are to be designed in accordance with Index 608.5 except where ramp widening is required to handle truck off-tracking, see Index 404.1. In such cases, the full ramp structural section should extend to the inside shoulder edge of the widened ramp, see Index 504.3(1)(b).

PCCP should be used for exit ramp termini where there is a high potential for exposure to heavy trucks, as discussed in Index 607.4.

608.7 Structural Section Design for Appurtenant Facilities

Following the pavement structural section design procedure for roadside rests and park and ride lots is not practicable because of the unpredictability of traffic. Therefore, standard sections, based primarily on arbitrarily chosen TI's, have been adopted.

(1) *Roadside Rest Pavement Design.* Table 608.7(1) gives recommended thicknesses for the elements of structural sections to be used on entrance and exit ramps, roads, truck parking areas and auto parking areas in safety roadside rests. The surface of the parking areas in safety roadside rests should be crowned or sloped to minimize the amount of surface water penetrating into the underlying layer. Good drainage of surface runoff should be provided.

Because traffic use of roadside rests is generally unpredictable, TI assumptions have been made which are the basis for Table 608.7(1). The structural sections are minimal, to keep initial costs down, but are reasonable because additional AC surfacing can be added later, if needed, and generally without incurring exposure to traffic or traffic handling problems. When stage construction is used to minimize initial costs, the full subbase and base thicknesses should be placed in the initial construction.

Table 608.7(1)

Structural Sections for Roadside Rests (Thickness of Layers[1] in mm)

Usage	TI	Material (Class)[3]	R-value of Basement Soil 50 & Over	45-49	40-44	35-39	30-34	25-29	20-24	15-19-	10-14	5-9
Ramps & Truck Roads	8.0	AC	75	90	90	105	75	75	75	75	75	75
		CTB(A)	180	180	210	210	180	180	180	180	180	180
		AS(2)	0	0	0	0	105	120	165	195	240	270
		AC	105	105	105	105	105	105	105	105	105	105
		AB(2)	195	240	270	330	195	195	195	195	195	195
		AS(2)	0	0	0	0	105	150	195	225	270	300
		AC[2]	195	210	225	240	255	270	285	285	285	300
Truck Parking Areas	6.0	AC	60	60	60	60	60	60	60	60	60	60
		AB(2)	135	165	195	210	135	135	135	135	135	135
		AS(2)	0	0	0	0	120	150	165	195	225	255
		AC[2]	120	135	150	165	165	180	195	195	210	210
Auto Roads	5.5	AC	60	60	60	60	60	60	60	60	60	60
		AB(2)	120	135	165	180	210	120	120	120	120	120
		AS(2)	0	0	0	0	0	120	150	180	210	225
		AC[2]	120	120	135	150	150	165	180	180	195	195
Auto Parking Areas	5.0	AC	45	45	45	45	45	45	45	45	45	45
		AB(2)	120	150	165	195	210	120	120	120	120	120
		AS(2)	0	0	0	0	0	105	135	165	180	210
		AC[2]	90	105	120	120	135	135	150	165	165	180

Notes:
1. AC thicknesses of 75 mm or less must be placed in one lift.
2. Full Depth AC option (No base or subbase).
3. Structural section material options listed for each Usage, TI and R-value are equivalent. The option chosen is the Project Engineer's decision based on recommendations from the District Materials Engineer, economics and material availability.

Table 608.7(1) considers R-value of the basement soil as the only variable under each traffic usage classification. Safety factors were applied in the ramp design but not for the other areas.

(2) *Park and Ride Lot Pavement Design.* The layer thicknesses shown in Table 608.7(2) are based primarily on successful district and local agency practice. These designs are minimal to keep initial costs down, but are considered reasonable since additional AC surfacing can be added later, if needed, without the exposure to traffic or traffic-handling problems typically encountered on a roadway.

The surface of Park and Ride Lots should be crowned or sloped to minimize the amount of surface water penetrating into the underlying layer. Good drainage of surface runoff should be provided. A 9.5 mm or 12.5 mm maximum AC mix is recommended to provide a relatively low permeability. The AC surfacing should be placed in one lift to provide maximum density.

Table 608.7(1), Structural Sections for Roadside Rests, should be used in designing the structural section for areas of park and ride lots that will be used by buses and/or trucks. Unique conditions may require other special considerations.

Table 608.7(2)
Structural Sections for Park and Ride Lots

R-Value Basement Soil	Thickness of Layers	
	AC* (mm)	AB (mm)
≥ 40	45	0
< 40	75	0
	45	105
≥ 60	Penetration Treatment, See Index 608.3(1)	

* Place in one lift.

Coal tar pitch emulsion treatment should not be applied to park and ride lots, however, a fog seal coat may be required after placing the AC, particularly if the facility will not be used shortly after construction.

Topic 609 - Selection of Pavement Type for New Construction

609.1 Introduction

The two types of pavement generally considered for new construction are rigid and flexible pavements as typified by portland cement concrete pavement (PCCP) and asphalt concrete pavement (ACP), respectively. There is no formula or clearcut procedure which will produce a definite answer as to which pavement type is the most appropriate. In addition, because physical conditions are so variable and the influence of other factors differs significantly from location to location, projects must be studied individually. Therefore, the Project Engineer must consider the factors in Index 609.2 and make certain assumptions and use engineering judgement based on the best knowledge available when determining which type to specify.

Whatever the factors are that control the selection of the pavement type, they should be documented in the permanent project history file.

A detailed economic comparison of pavement types (see Index 609.3) must be performed. Exceptions to this requirement are permitted under the following conditions:

(a) Where an existing pavement will be widened or resurfaced with a similar material.

(b) Where the new pavement length is less than 6.5 lane kilometers.

(c) Where the design of the roadway allows periodic inundation the use of portland cement concrete pavement is recommended.

(d) Where it is economically unreasonable to locate and construct the highway so that unequal settlement or expansion will be eliminated, thus dictating the use of asphalt concrete pavement.

(e) Where short freeway to freeway connections are being made between pavements of the same type.

When detailed economic comparisons are not made, the reasons must be stated fully in the pavement type submittal, per Index 602.1(4).

609.2 Pavement Type Determination

The choice of pavement type should consider the following factors, which are listed and discussed in Appendix B of the AASHTO Guide for Design of Pavement Structures. Primary factors listed are:

(a) Traffic,

(b) Soils characteristics,

(c) Weather,

(d) Construction considerations,

(e) Recycling, and

(f) Cost comparisons.

No significance is attached to the order in which the factors are listed. These factors should be considered and addressed specifically in all project approval documents (PR, PSSR, etc.).

Secondary factors which may be pertinent should also be considered and a statement made that they have been considered. These factors include:

- Performance of similar pavements in the project area.
- Adjacent existing pavements.
- Conservation of materials and energy.
- Availability of local materials or contractor capabilities.
- Traffic and worker safety.
- Incorporation of experimental features.
- Stimulation of competition.
- Municipal preference, participating local government preference and recognition of local industry.

Another consideration that may have a possible effect on the final decision is the presence of grade controls, such as median barriers, drainage facilities, lateral and overhead clearances, and structures which may limit the structural section design or rehabilitation strategies. The pavement type selection should consider how these appurtenant features affect the pavement structural section.

The new construction design or rehabilitation strategy should also minimize the exposure and maximize the safety of the construction or maintenance forces and their equipment.

After considering the various governing factors and other specific items involved with the project under study, alternative structural sections should be developed for analysis. Once the alternative structural sections are chosen, an economic analysis must be done. If a detailed analysis is not required, per Index 609.1, a less comprehensive analysis must still be done. This analysis is basically to consider the most economical structural section elements among the various alternatives.

If a detailed economic analysis is required, it should follow the procedure in Index 609.3. It is important to note that economics alone does not always dictate the final choice for structural sections or their alternative elements. After analyzing all of the information available, the new structural section or rehabilitation strategy is chosen and submitted in accordance with Index 602.1.

609.3 Economic Analysis

Life-cycle economic comparisons must be made between properly designed structural sections that would be approved for construction if selected. The structural section chosen in the economic comparison must be included in the final plans unless a revision is subsequently approved. In this event a short memorandum is prepared referring to the original documentation, stating the details of the change, the reasons for the change, and the revised life-cycle costs. See Index 602.1 for documentation requirements.

(1) *General Economic Comparison.* The economic comparison of structural sections should be based on total expected life-cycle cost. The following general guidelines should be used:

(a) The structural sections to be compared should be shown by sketches so that quantities can be computed and checked.

(b) A 35-year economic life-cycle period should be used for each project. This assumes that the pavement structural section will be maintained and rehabilitated to carry the projected traffic over a 35-year period.

(c) A discount rate of 5% is used to convert costs to present worth.

(d) Life-cycle costs are to be computed for the entire pavement structural section, including shoulders, for a length of one kilometer in one direction of travel on divided highways. The entire structural section is included for 2-lane roadways.

(2) *PCC Pavement Structural Section.* The life-cycle cost analysis for a PCCP structural section should include the following items as appropriate:

(a) Initial Costs.

- PCCP,
- Treated base (LCB, ACB, ATPB, CTPB),
- Aggregate base (AB),
- Aggregate subbase (AS),
- Shoulders,
- Shoulder base,
- Shoulder subbase,
- Structural section drainage system (TPB layer under PCCP and/or edge drains), and
- Joint seal.

(b) Maintenance Costs.

- Maintenance (seal joints and cracks, slab jacking, undersealing to fill voids, repair spalls or broken slabs, occasional slab replacement, etc.), and
- Traffic delay.

(c) Rehabilitation Costs.

- Grooving all lanes in year 15,
- Replacing 10 - 15 slabs per lane kilometer in truck lanes in year 15,
- Placing a 105 mm AC overlay with interlayer (preceded by slab cracking and seating) in year 25,
- Engineering cost (preliminary and construction charges as percent of rehabilitation costs determined from past district records),
- Appurtenant and supplemental work (all work to be done to appurtenant drainage, safety, and other features made necessary by the rehabilitation work),
- Traffic delay (obtain cost data from District Division of Planning),
- Detours (may be included in appurtenant and supplemental work), and
- Salvage value (estimated remaining service life of pavement or value of structural section materials).

(3) *ACP Pavement Structural Section.* The life-cycle cost analysis for an ACP structural section should include the following items:

(a) Initial Cost.

- ACP,
- Base (LCB, ACB, CTB, ATPB, CTPB, AB),
- Aggregate subbase (AS),
- AC shoulders,
- Shoulder base, and
- Shoulder subbase.

(b) Maintenance Cost.

- Maintenance (thin AC blanket, chip seals, patching, sealing cracks, etc.), and

- Traffic delay.

(c) Rehabilitation Cost.

- 45 mm AC overlay or equivalent hot recycle alternate for all lanes and shoulders once every 12 years,

- Engineering cost (preliminary and construction charges as percent of rehabilitation costs determined from past district records),

- Appurtenant and supplemental work (all work to be done to appurtenant drainage, safety, and other features made necessary by the rehabilitation work),

- Traffic delay (obtain costs from District Division of Planning),

- Detours (may be included in appurtenant and supplemental work), and

- Salvage value (estimated remaining service life of pavement or value of structural section materials).

The computation of present worth cost for one pavement type can be stated as the formula:

Present worth cost =

Initial cost + [(Rehabilitation costs + Engineering Cost + Supplemental Work Cost + Traffic Delay Cost) x Present Worth Factor Number 1] + [(Maintenance costs) x Present Worth Factor Number 2] - [(Salvage value) x Present Worth Factor Number 3].

Using symbols, this also can be expressed as follows:

PWC = IC + [(RC + EC + SC + DC) x PWF No. 1] + (MC x PWF No. 2) - (SV x PWF No. 3)

Where:

PWC	=	Present worth cost
IC	=	Initial cost
RC	=	Rehabilitation cost
EC	=	Engineering cost
SC	=	Supplemental work cost
DC	=	Traffic delay cost
PWF	=	Present worth factor
MC	=	Maintenance cost
SV	=	Salvage value

It is imperative that careful attention be given to the calculations involved and the data used in the calculations to insure the most realistic and factual comparison between pavement types and rehabilitation strategies.

An economic life-cycle cost comparison format for a 35-year period is presented in Table 609.3.

Topic 610 - Structure Approach Pavement and Structure Abutment Embankment Design

610.1 Introduction

The ultimate goal of structure approach slab design is to provide a smooth transition between a pavement that is generally supported on a yielding medium (soil that is subject to consolidation and settlement) and a structure which is supported on a relatively unyielding foundation (piling or spread footings).

The approaches to any structure, new or existing, often present unique geometric, drainage, structural section, and traffic situations that require special design considerations.

Adequate information must be available early in the project development process if all factors affecting the selection and design of a structure approach system are to be properly assessed. A field review will often reveal existing conditions which must be taken into consideration during the design.

Table 609.3
Life-Cycle Economic Comparision of Pavement Types (35-Year Analysis Period and 5% Discount Rate)

PORTLAND CEMENT CONCRETE PAVEMENT (PCCP)			Cost Per Kilometer With Shoulders
Initial Cost =			$(_A_)
Rehabilitation at 15 years (grooving and truck lane slab replacement):			
Cost =		$(_b_)	
Engineering	$(_b_)(0.1225) =	$(___)	
Appurtenant and Supplemental Work	$(_b_)(0.1350) =	$(___)	
Traffic Delay =		$(___)	
		$(_c_)	
Present Worth of 15-year Rehabilitation		$(_c_)(0.4810) =	$(_C_)
Rehabilitation at 25 years (Crack, Seat, and 105 mm AC Overlay):			
Cost =		$(_d_)	
Engineering	$(_d_)(0.1225) =	$(___)	
Appurtenant and Supplemental Work	$(_d_)(0.1350) =	$(___)	
Traffic Delay =		$(___)	
		$(_e_)	
Present Worth of 25-year Rehabilitation		$(_e_)(0.2953) =	$(_E_)
Maintenance for 35 years (See Index 609.3(2)(b))		$(_*_)(16.3742)=	$(_F_)
	Subtotal (A+C+E+F)		$(___)
	Less Salvage Value (of rehabilitation)**	(2/12) $(_c_)(0.1813) =	- $(___)
PCCP Net Present Worth Cost			$(___)

ASPHALT CONCRETE PAVEMENT (ACP)			Cost Per Kilometer With Shoulders
Initial Cost =			$(_G_)
Rehabilitation (45 mm Overlay or Hot Recycling 45 mm):			
Cost =		$(_h_)	
Engineering	$(_h_)(0.1225) =	$(___)	
Appurtenant and Supplemental Work	$(_h_)(0.1350) =	$(___)	
Traffic Delay =		$(___)	
		$(_i_)	
Present Worth of Rehabilitation at 12 years		$(_i_)(0.5568) =	$(_I_)
Present Worth of Rehabilitation at 24 years		$(_i_)(0.3101) =	$(_J_)
Maintenance for 35 years (See Index 609.3(3)(b))		$(_*_)(16.3742)=	$(_K_)
	Subtotal (G+I+J+K)		$(___)
	Less Salvage Value (of Resurfacing) **	(1/12) $(_i_)(0.1813) =	- $(___)
ACP Net Present Worth Cost			$(___)
Savings Per Kilometer Using (PCCP/ACP)	[Circle appropriate pavement type]		$(___)

NOTES

* As an initial estimate, use the average annual district maintenance cost for the respective type of pavement.

** Salvage Value Assumptions: For purposes of this example, the original PCCP is expected to require some type of rehabilitation work at 15 and 25 years. At the end of the 35-year comparison, the second rehabilitation is expected to serve 2 years longer. This provides a salvage value of 2/12 the cost of the second rehabilitation. The original ACP is expected to require resurfacing or recycling in 12 and 24 years, and the 45 mm AC overlay or recycling is assumed to last 12 years for a total service of 36 years.

These design guidelines must be followed in the design of all projects involving new construction, reconstruction or rehabilitation of structure approaches. They are not, however, a substitute for engineering knowledge, experience, or judgment.

610.2 Functional Area Responsibilities

Investigations by the Office of Structural Foundations (OSF) Structure Foundation and/or Roadway Geotechnical Engineering Branches, District Materials Unit, and District Division of Operations will generally be necessary for complete analysis of the structure approach foundation and embankment conditions, seismic concerns, and traffic handling.

A foundation investigation and analysis should be performed by the OSF Structure Foundation Branch on new construction projects. At the request of the Division of Structures (DOS), the OSF Roadway Geotechnical Engineering Branch will prepare a Geotechnical Design Report based upon its studies and information supplied by the District. The report should include a summary of field investigations, estimate of settlement by areas, specific recommendations for foundation treatment, and a history of the performance of structure abutment foundations and embankments in the same area. All foundation and embankment recommendations by the OSF Branches must be carefully followed in development of the project PS&E.

The District Materials Unit is responsible for conducting a preliminary soils investigation which addresses the quality of the materials available in and under the roadway prism for constructing the project. Poor quality material, such as expansive soils, must be precluded from structure abutment embankments. If sufficient quality roadway excavation material is unavailable for constructing structure abutment embankments, the designer may specify select material, local borrow or imported borrow to satisfy the design requirements.

Quality requirements for embankment material are normally specified only in the case of imported borrow. When select material or local borrow for use in structure abutment embankments is shown on the plans, the Resident Engineer (RE) is responsible for assuring the adequacy of the quantity and quality of the specified material. The RE File should include adequate information and guidance to assist the RE in fulfilling this responsibility.

On rehabilitation projects, complete investigations by the District Division of Operations will be necessary to assess the impact of lane closures and detours on the traveling public. Recommendations by the District Division of Operations staff should be followed when developing the project PS&E.

On new construction projects, the DOS is responsible for determining whether or not a concrete pavement approach system is used at each bridge site. On rehabilitation projects, the Pavement Rehabilitation Scoping Team will recommend whether or not replacement or construction of a PCC approach slab(s) is necessary.

When the construction or rehabilitation of a concrete pavement approach is necessary, the DOS is responsible for selecting the type of concrete approach system to be used.

The Project Engineer (PE) should contact the District Liaison Engineer as early as possible in the project development process to facilitate project scheduling. The PE must provide pertinent site information to DOS and may submit recommendations concerning the need for concrete approach systems. Close coordination between the District staff and DOS staff is necessary for the proper selection and design of a structure approach system.

The PE is responsible for the Plans, Specifications, and Estimate (PS&E) of all structure approach contract items below the grading plane, except for the contiguous drainage system components placed within the abutments and wingwalls. The PE is responsible for PS&E of drainage outside the abutments and wingwalls. Figure 610.2A shows the limits of structure approach embankment material requiring 95% relative compaction for which the PE is responsible. The PE is also responsible for coordinating and reviewing the adequacy of all drainage ties between the structure approach drainage features and other new or existing drainage facilities.

DOS is responsible for the PS&E of all structure approach contract items above the grading plane and for the drainage system components placed within the abutments and wingwalls. Questions

Figure 610.2A

Limits of Structure Approach Embankment Material

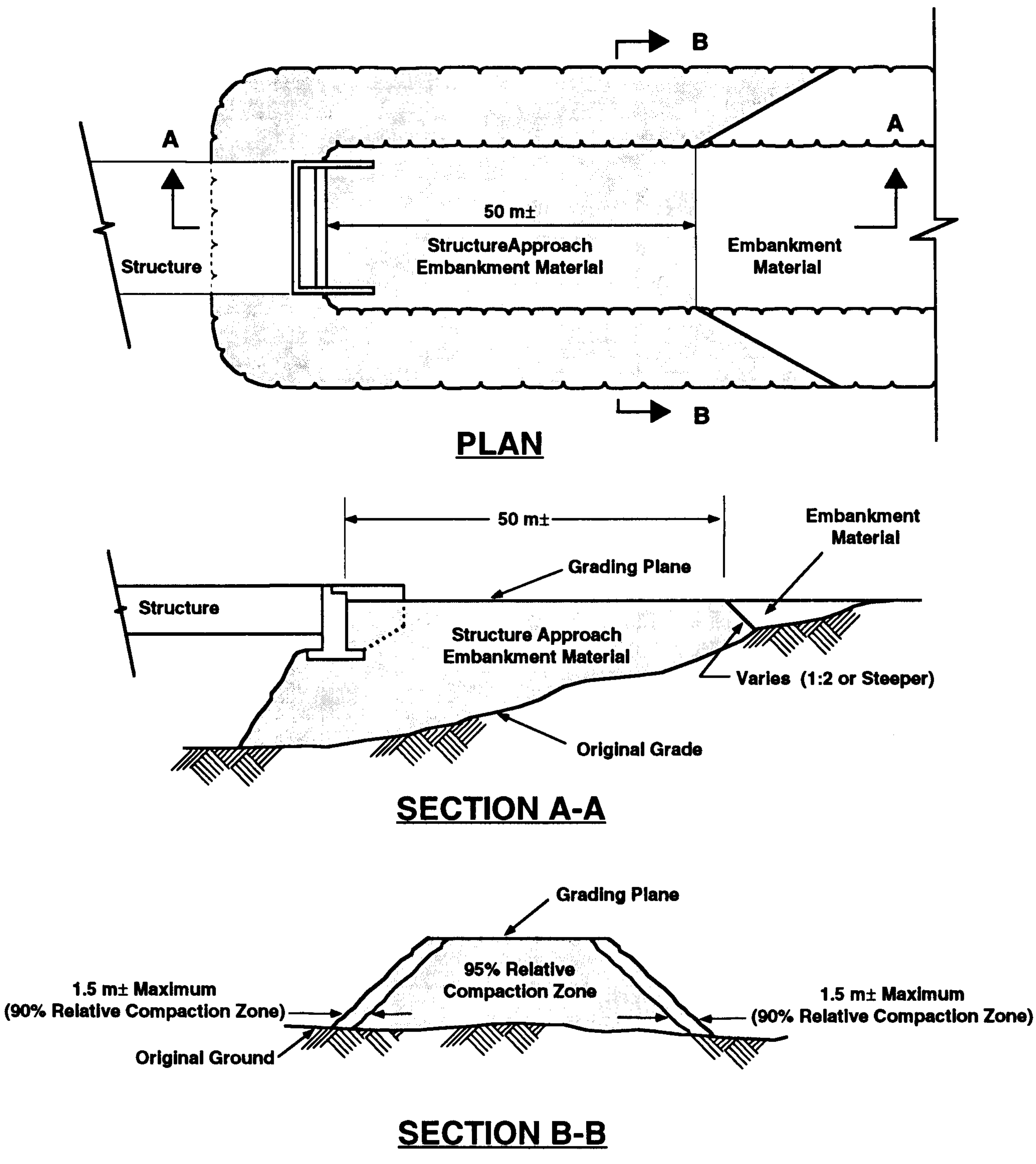
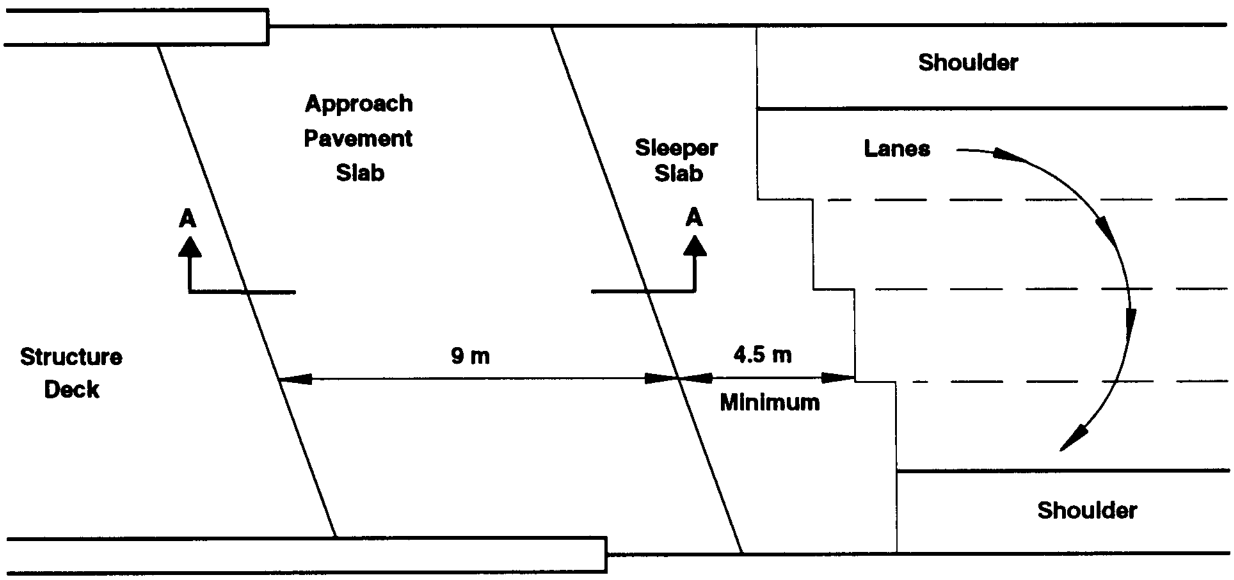
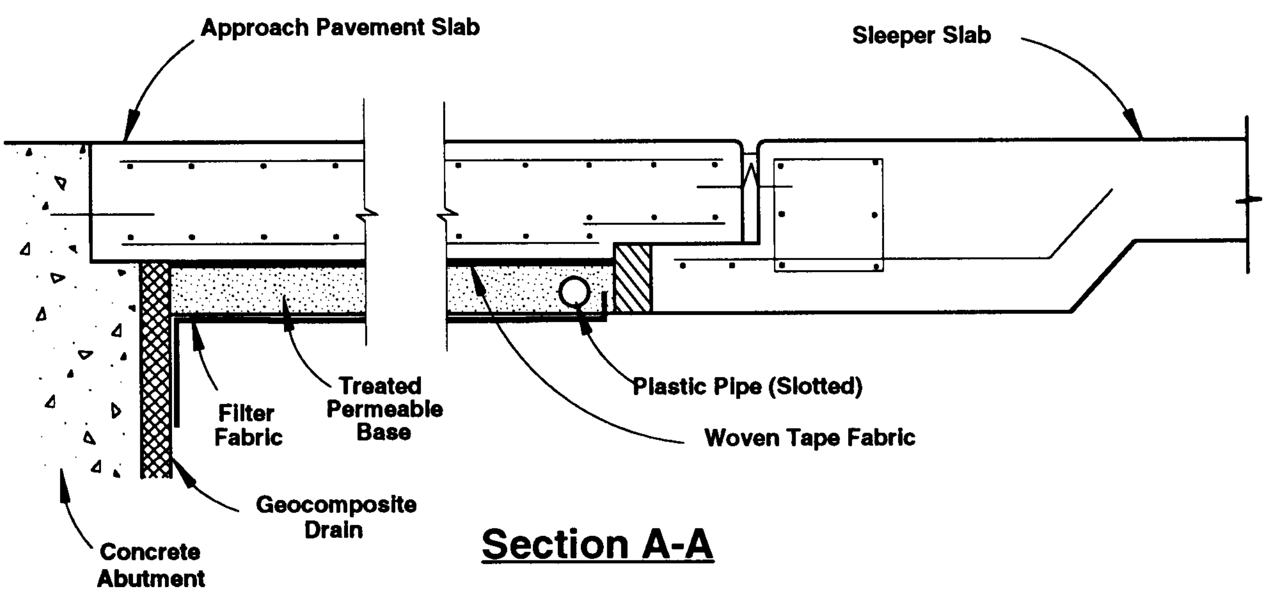


Figure 610.2B

Type 45 Structure Approach Layout



Plan View



Section A-A

Figure 610.2C
Approach Slab Edge Details

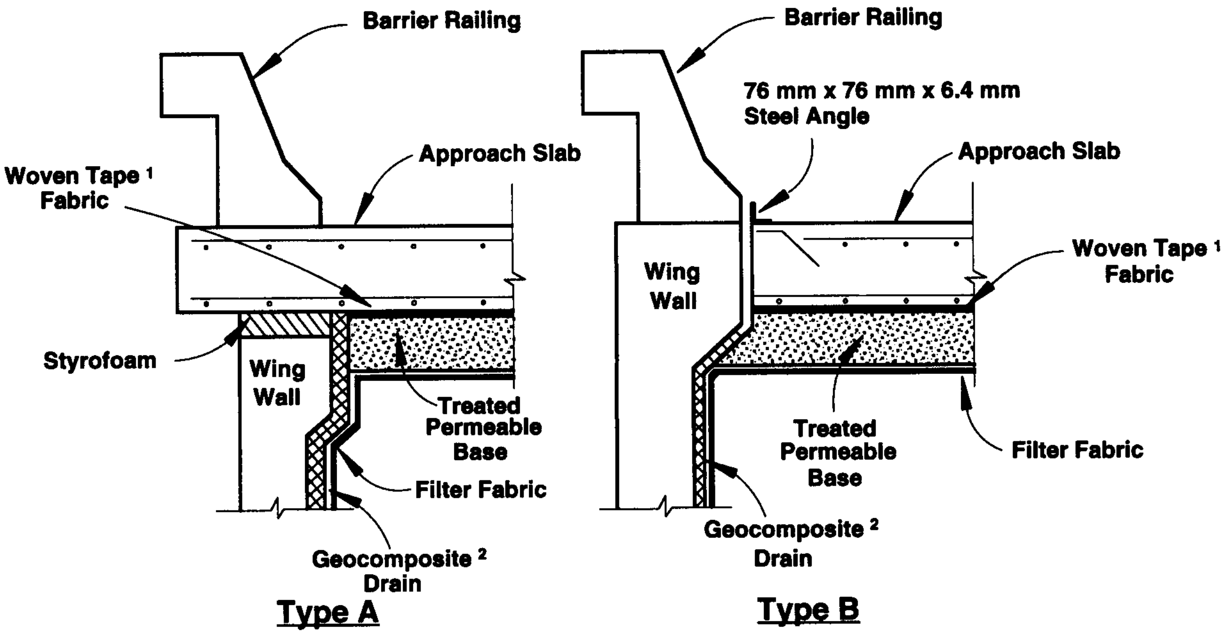
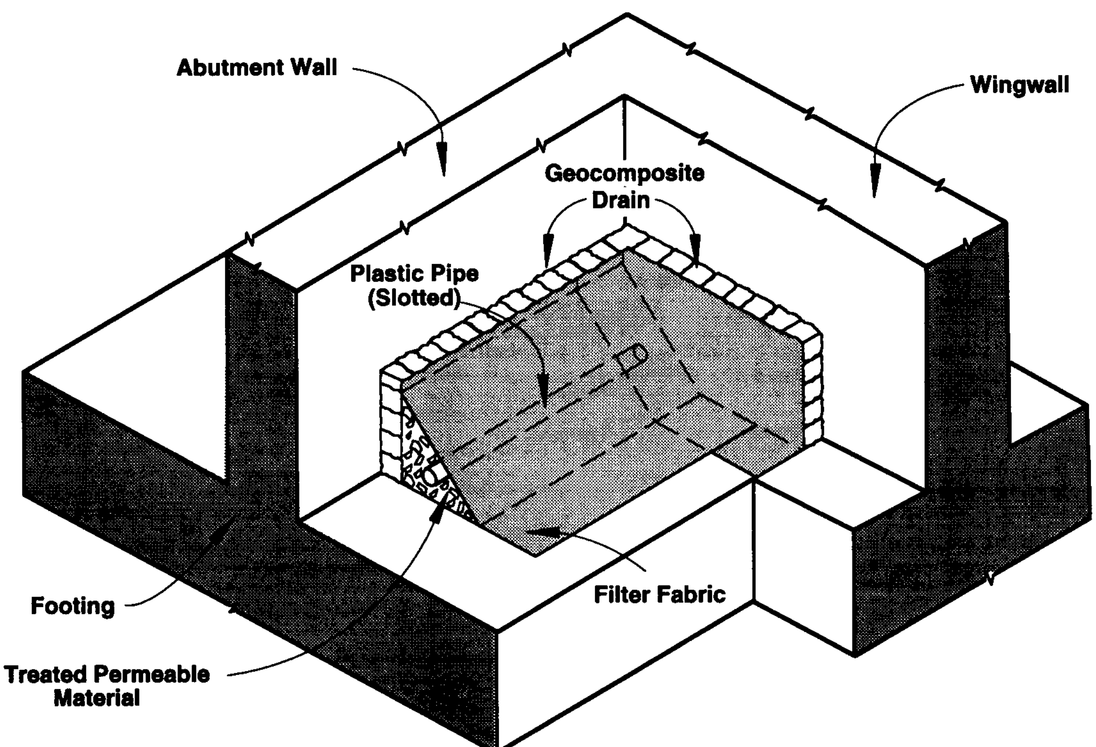


Figure 610.2D
Abutment Drainage Details[2]



NOTES:
1. Applicable to Type 45 Structure Approach Systems only.
2. Applicable to new construction only.

concerning approach slab design should be directed to DOS. Figures 610.2B, 610.2C and 610.2D show diagrammatically the structure approach features which are DOS responsibilities.

Special attention to the structure approach plans, special provisions and specifications during all phases of construction will be required on the part of both the structure and highway construction inspectors.

610.3 Structure Approach Pavement Systems

Concrete pavement approach systems are used on all portland cement concrete pavements (PCCP) and on multilane asphalt concrete pavements (ACP) located within currently designated urbanized areas. Urbanized areas are identified, by kilometer post, in the Route Segment Report, Project Management Control System (PMCS) Data Base and State Highway Inventory. The current boundaries of urbanized areas are also shown on the official State Highway Map.

There are several pavement slab alternatives that may be considered in the design of a structure approach pavement system. These alternatives are designated Types 45, 30, and 10 structure approach systems. Standard details and special provisions have been developed for each type of approach system. DOS will select the appropriate alternate and include applicable details and specifications in the PS&E.

On all new construction projects (PCCP or ACP), regardless of the type of structure approach selected, provisions for positive drainage of the approach system are to be incorporated into the design.

On rehabilitation projects, provisions for positive drainage of the structural section must be incorporated into the structure approach design.

On new construction projects, overcrossing structures constructed in conjunction with the State highway facility should receive the same considerations as the highway mainline.

A brief discussion of the types of structure approach pavement systems follows:

(1) Type 45 Structure Approach System (Approach and Sleeper Slabs/Drainage).

The Type 45 system includes a 9 m long reinforced concrete pavement slab and a 4.5 m long structure approach sleeper slab. The structure approach system extends laterally across all traffic lanes and shoulder areas. The approach slab is designed to either cantilever over (preferred) or extend to the inside faces of both abutment wingwalls.

The Type 45 approach system is used only on new construction with structures having diaphragm type abutments. It is primarily used on PCCP but may be used on ACP if warranted by special site conditions.

(2) Type 30 Structure Approach Pavement System (Approach Slab/Drainage). This approach slab is a 9 m long reinforced concrete pavement slab which rests on and is tied to the structure abutment backwall or paving notch. The slab extends laterally across all traffic lanes and shoulder areas. The approach slab is designed to either cantilever over or extend to the inside faces of both abutment wingwalls.

The Type 30 system is the design standard for new construction at structures with seat type abutments. The Type 30 system is also adaptable to diaphragm type abutments where the Type 45 approach system may be inappropriate. The Type 30 slab is the standard rehabilitation treatment at structures with either diaphragm or seat type abutments.

(3) Type 10 Structure Approach Pavement System - Earthquake Zones (Seismic Ramp Slab). The Type 10 structure approach slab, 3 m in length, is used only on ACP located within areas of high magnitude seismic activity. This approach slab is designed to provide a ramp to accommodate the passage of motor vehicles over the structure in the event that an earthquake creates settlement of the structure abutment embankment and approach pavement. The Type 10 seismic ramp slab is provided when both conditions (a) and (b) exist or when condition (c) exists:

(a) Peak rock acceleration is estimated to be 0.6 x gravity or greater, as documented in the Geotechnical Design Report, Materials Report or Foundation Report.

(b) Approach embankment or fill height exceeds 3 m.

(c) Geologic conditions, as documented in the Geotechnical Design Report, Materials Report or Foundation Report, indicate the need for a seismic approach ramp.

If an alternate and convenient route is available for use by emergency vehicles, the use of the Type 10 structure approach system is not necessary.

610.4 Structure Approach Pavement System - New Construction

(1) Foundation and Embankment Design. The structural stability and overall performance of the structure approach system depends, to a significant degree, upon the long term settlement/ consolidation of the approach foundation and structure abutment embankment. A design that minimizes this post construction settlement/ consolidation is essential. Factors that influence settlement/ consolidation include soil types and depths, static and dynamic loads, ground water level, adjacent operations, and changes in any of the above. All foundation and embankment recommendations by the OSF Branches and District Materials Unit must be carefully followed by the PE, and any significant deviations from their recommendations must be approved by them.

The relative compaction of material within the embankment limits, shown in Figure 610.2A, must not be less than 95%, except for the outer 1.5 m of embankment measured horizontally from the side slope. The District Materials Engineer or OSF may recommend using select material, local and/or imported borrow to assure that the compaction requirements are met and that shrink/swell problems are avoided. They may also recommend a height and duration of embankment surcharge to accelerate foundation consolidation.

(2) Abutment Details. The Type 45 approach slab is rigidly tied to the structure abutment and acts as an extension of the structure. Any movement of the abutment will also occur in the approach slab. A sealed joint between the approach slab and the sleeper slab, parallel to and 9 m from the abutment wall, provides for this movement.

The Type 30 approach system is used at structures having either diaphragm or seat type abutments. At a diaphragm type abutment, structure movement is accommodated at the sealed joint between the approach slab and abutment. Structure movement at a seat type abutment will occur at the structure side of the abutment. The structure/abutment joint is designed to handle the movement.

The Type 10 approach system is also used at both seat and diaphragm type abutments. Various abutment/slab tie details are available to accommodate structure movement.

(3) Structure Approach Drainage. Special attention must be given to providing a positive drainage system that minimizes the potential for water damage to the structure approach embankment. The following features should be included:

(a) Abutment and Wingwall Drainage

A geocomposite drain covered with filter fabric is used behind both the abutment wall and wingwalls, as indicated in Figures 610.2B, 610.2C, and 610.2D.

A slotted plastic pipe drain, encapsulated with treated permeable material, is placed along the base of the inside face of the abutment wall as illustrated in Figure 610.2D. A pipe outlet system carries the collected water to a location where it will not cause erosion. Coordination with DOS is necessary for the exit location of the pipe system. The outlet type should be chosen from the standard edge drain outlet types shown in the Standard Plans. The PE must review the drainage design to insure the adequacy of the drainage ties between the abutment and wingwall drainage system and either new or existing drainage facilities.

(b) Structural Section Drainage

Figure 610.2B shows the components of the positive structural section drainage system. Filter fabric should be placed on the grading plane to minimize contamination of the treated permeable base (TPB) for all types of approach systems. For the Type 45 approach system, a transverse slotted plastic pipe is installed in the treated permeable layer under the approach slab and adjacent to the sleeper slab to intercept water that enters through this joint. The plastic pipe should have a proper outlet to avoid erosion of the structure approach embankment.

(c) Surface Drainage

Roadway surface drainage should be intercepted before reaching the approach/sleeper slab; likewise, structure deck drainage, when practicable, should be intercepted before reaching the abutment joint or paving notch. The objective is to keep water away from the structure approach embankment. The surface water, once collected, should be discharged at locations where it will not create erosion.

Containment of surface drainage requires special treatment when the approach slab edge extends only to the inside faces of the abutment wingwalls. A 76 mm x 76 mm x 6.4 mm steel angle (see Figure 610.2C), pourable seal, and hardboard spacer prevent water from entering the structural section and embankment. On wingwalls longer than 9 m, the angle is terminated at the sealed joint between the approach slab and the sleeper slab.

When an AC dike is required to protect the side slope from erosion, it should be placed on the approach and sleeper slabs and aligned to tie into the end of the structure railing. The guardrail alignment and edge of shoulder govern the positioning of the AC dike.

When the Type 45 approach system is used, the AC dike will inevitably crack due to expansion and contraction at the approach/sleeper slab joint. A metal dike insert is used to carry the flow across the sealed joint. The insert acts as a water barrier to minimize erosion of the fill slope. Details of the metal dike insert are shown in the structure approach plans provided by DOS.

(4) Pavement Details. Approach/sleeper slabs extend the full width of the traveled way and shoulders. On new construction, or rehabilitation work where the structure railing will be replaced, the approach slab extends laterally to coincide with the edge of the structure superstructure. The slab extends over the wingwall, but is separated from the top of the wingwall by styrofoam fillers to preclude vertical loading of the wingwalls when settlement of the embankment occurs. The new structure railing is then attached to the approach slab.

The Type 45 approach slab system utilizes a woven tape fabric which is used as an interlayer separator on top of the treated permeable base to reduce friction and accommodate movement of the approach slab. The sleeper slab functions as a bearing surface for the approach slab in the event that settlement/consolidation of the structure abutment foundation or embankment occurs. The sleeper slab also functions as a transition slab to the pavement structural section.

Any longitudinal construction joints (cold joints) required during construction of the structure approach or sleeper slabs should be placed on lane lines. The contact joint at the end of the sleeper slab is normal to the centerline. Transverse joints may be staggered at the lane lines at skewed structures; as illustrated in Figure 610.2B. The stagger may occur 7.2 m or 10.8 m apart for skews of 30 degrees or less and at each lane line for skews greater than 30 degrees.

(5) Guardrail. The extension of the approach and sleeper slabs across the full width of the outside shoulder creates a conflict between the outside edge of these slabs and the standard horizontal positioning of some guardrail posts. Douglas fir block spacers are attached to the posts that conflict with the approach and sleeper slabs to move the post holes outside the edge of shoulder without changing the standard alignment of the guardrail. These details are covered by DOS Standard Details and by Standard Plans.

610.5 Structure Approach Slab - Rehabilitation Projects

(1) *Approach Slab Replacement.* The Type 30 approach slab is the primary rehabilitation standard for both PCCP and ACP. The Type 10 approach slab may be used on ACP only, if warranted by special site considerations (see Index 610.3).

Replacement of a PCC approach slab consists of removing the existing pavement, approach slab, cement treated base and subsealing material (if applicable) and then replacing with an appropriate type of structure approach system. Depending on the thickness of the existing pavement and base materials to be removed, the minimum 300 mm approach slab thickness (Type 30 approach system) may have to be increased.

(2) *Structure Approach Drainage.* Typical details for positive drainage of a full-width structure approach system are shown in Figure 610.5A. Cross drains are placed at the abutment backwall and at the transverse joint between the existing pavement and the concrete approach slab. A collector/outlet system is placed adjacent to the wingwall at the low side of pavement. The collected water is carried away from the structure approach embankment to a location where it will not cause erosion.

The approach slab edge details to prevent entry of water at the barrier rail face (see Figure 610.2C - Type B) apply when the wingwalls and/or bridge barrier railing are not being reconstructed.

(3) *Pavement Details.* Special pavement details are necessary when PCC approach slabs will be replaced in conjunction with the crack, seat and AC overlay pavement rehabilitation strategy for PCCP. Figure 610.5B, which is applicable to full-width slab replacement, illustrates a method of transitioning from the typical 105 mm AC overlay thickness to the minimum 45 mm final AC lift thickness. Care should be taken in areas with flat grades to avoid creating a ponding condition at the structure abutment.

Cracking and seating of the existing PCCP as well as the pavement reinforcement fabric (PRF) should be terminated at the start of the transition from the 105 mm AC overlay depth.

Prior to placing an AC overlay across a structure deck, the PE should contact the Office of Structures Maintenance regarding the structural adequacy of the structure and other considerations. If an AC overlay is permissible, then the Office of Structure Design should be consulted to provide the necessary details.

(4) *Composite Pavements.* Flexible (AC) surfacing over rigid (PCC) pavement is considered to be a rigid pavement for structure approach rehabilitation. The guidelines for rigid pavement apply to all composite pavement rehabilitation projects which include structure approach slab replacements.

(5) *Traffic Handling.* Traffic handling considerations generally preclude full-width construction procedures. Structure approach rehabilitation is therefore usually done under traffic control conditions which require partial-width construction.

District Division of Operations should be consulted for guidance on lane closures and traffic handling.

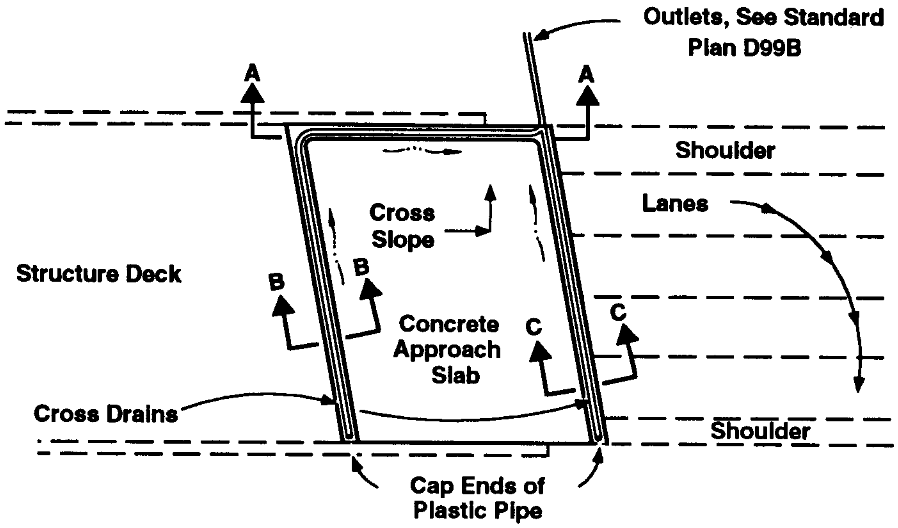
Topic 611 - Pavement Structural Section Rehabilitation

611.1 Introduction

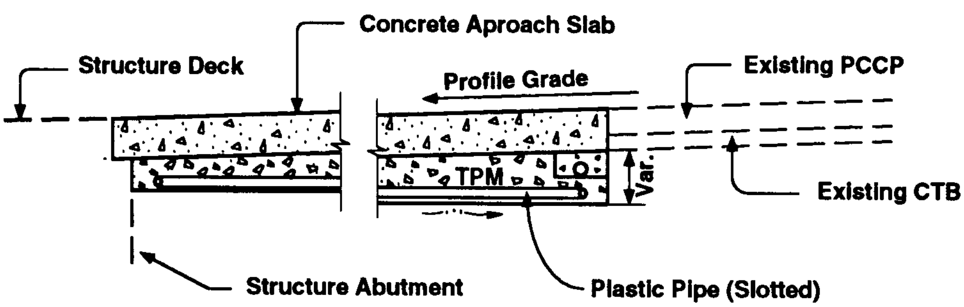
Pavement throughout the state is showing varying degrees of distress and is in need of preventive or corrective maintenance, or rehabilitation. Corrective or preventative maintenance or rehabilitation may be needed to restore ride quality and minimize excessive maintenance costs. Rehabilitation may be needed to restore ride quality and structural integrity.

Caltrans is continually researching and evaluating new rehabilitation materials, methods and strategies for pavement maintenance and rehabilitation. Since this is an area of rapidly changing technology, the rehabilitation guidelines presented under Topic 611 are not

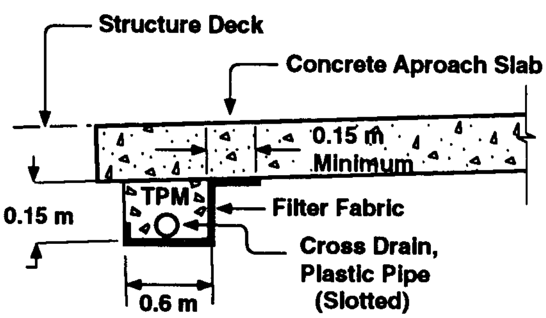
Figure 610.5A
Structure Approach Drainage Details
(Rehabilitation)



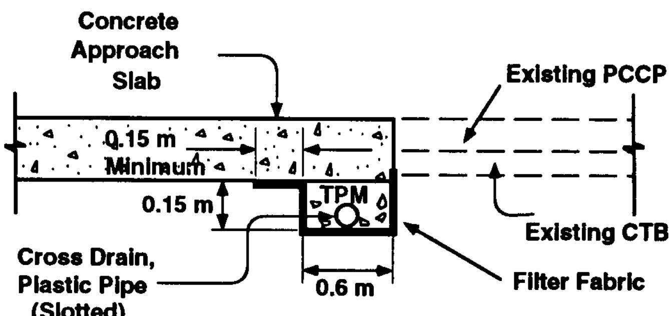
PLAN



SECTION A-A



Section B-B



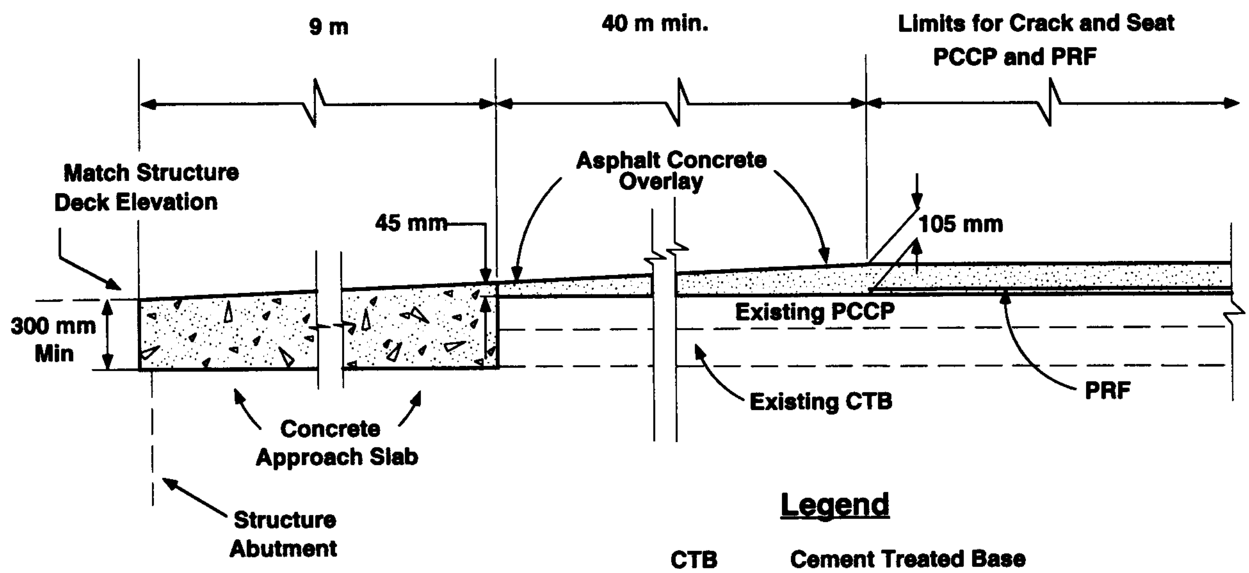
Section C-C

Legend

—··—►	Direction of Flow
CTB	Cement Treated Base
PCCP	Portland Cement Concrete Pavement
TPM	Treated Permeable Material

Figure 610.5B

Structure Approach Pavement Transition Details (Rehabilitation)



Legend

CTB	Cement Treated Base
PRF	Pavement Reinforcing Fabric
PCCP	Portland Cement Concrete Pavement

intended to rule out other alternatives that may be appropriate. Project decisions should be based on a multifunctional engineering team effort which includes a careful review and analysis of all pertinent factors for each project.

Caltrans has adopted an abbreviated review process for pavement rehabilitation projects which involves a multifunctional team that meets in the field or office on short notice to expedite the project approval process and ultimately the project design. The Project Scoping Team includes employees with a depth of experience and background which assures that all pertinent factors are considered.

The Scoping Team reviews are scheduled and coordinated by the District. Final project approval is by the District Director. See the Project Development Procedures Manual for details.

611.2 Pavement Management System

(1) *General.* Caltrans developed and adopted a Pavement Management System (PMS) in the late 1970's which emphasizes an engineered approach to pavement rehabilitation, and a structured systems approach for the system-wide management of existing pavements.

The PMS is the primary tool used in determining where repairs are needed and how available funds will be apportioned statewide. It involves the following step-by-step processes:

- Inventorying pavement conditions.
- Analyzing the extent and severity of pavement distress.
- Identifying potential cost effective repair strategies and potential alternatives for candidate projects.
- Relating the repair strategies to the appropriate Caltrans highway program structure.
- Developing a candidate project list for each district and statewide, based on "triggering" factors, a "decision tree", analysis and a priority system.

The PMS is used by the Programming Program to assist in programming and scheduling improvements according to Departmental rehabilitation policies and to promote a more uniform level of pavement performance statewide. The PMS reports are used by the PE, as a starting point, in the determination of the appropriate repair strategy for rehabilitation and capital preventive maintenance (CAPM) projects.

(2) *PMS Reports.* The PMS uses data gathered every two years in a statewide pavement condition survey. This survey of the physical condition and ride quality of all through lanes of the California State Highway System is fully documented.

The information obtained during the pavement inventory survey is compiled into various user reports. These reports have been designed to provide a limited array of report formats, thereby minimizing the volume of information furnished and providing maximum capability and flexibility for selecting and sorting information. These reports identify where rehabilitation should be considered, indicate a potential repair strategy, provide repair cost and expected service life, quantify rehabilitation costs, support program funding levels, and aid in determining program and project priorities for programming improvements.

Three basic reports are developed. These are:

(a) Pavement Condition Inventory
  - Flexible Pavement
  - Rigid Pavement
  - Structure Approach Ride Rating

(b) Candidate Location Priority List:
  - Reconstruction and Restoration Program (HA22)

(c) Potential Corrective Strategies for All Triggered Lanes (containing all triggered problems and potential repair strategies for each lane).
  - Reconstruction and Restoration Program (HA22)
  - Flexible Pavement Maintenance Program (HM1A)

- Rigid Pavement Maintenance Program (HM1B)

The Project Development Procedures Manual requires that all Project Scope Summary Reports (PSSRs) for roadway rehabilitation, reconstruction, and restoration projects include the latest Pavement Management System Inventory Report for the pavement segment included in the project limits.

611.3 Pavement Rehabilitation Project Development Procedures

Special project development procedures which include those mentioned in Index 611.1, are followed in the development and design of pavement rehabilitation projects in order to reduce the lag time between the recognition of pavement deterioration symptoms and construction of the project. These procedures are covered in the Project Development Procedures Manual.

611.4 General Pavement Structural Section Failure Types

Engineering judgment, based primarily on experience in pavement design, construction, materials, and maintenance, is required to identify pavement failure types and to determine the primary source of failure. With experience in these areas an observer can generally determine whether the failure is primarily in the pavement layer, the base and/or the subbase, or in the basement soil. Where there is no significant visual distortion in the riding surface, the failure can generally be assumed to be confined to the pavement layer.

In portland cement concrete pavement (PCCP) with basement soil problems, surface distortion is most commonly manifested in the form of uneven tipping of slabs or broken slab segments and sometimes by differential movement at joints. Step faulting at weakened plane transverse joints of uncracked slabs or at both transverse joints and intermediate transverse cracks, without uneven distortion, indicates that the problem is primarily confined to the structural section. A combination of the above conditions would indicate the problem is both in the structural section and basement soil.

In asphalt concrete pavement (ACP), base or subbase failure may be visually indicated by the rutting of the AC surface in the wheel paths or by alligator cracking of the AC. On the other hand, deep rutting may also indicate a lack of stability in the AC. Meandering cracks and differential settlement of the surface most likely indicates a subsurface problem.

There are many variables in materials and environment as well as other factors that affect the performance of pavement structural sections. This makes it impossible to develop hard and fast rules for the rehabilitation of pavements. Therefore, the PE should rely on the experience, judgment and guidance of engineers in pertinent functional engineering areas who are familiar with the design, construction, materials, and maintenance of pavement in the geographical area of the project. Deflection testing of ACP, coring of PCCP and other tests can be used to confirm judgments that are made.

The following discussion of pavement failure types for PCCP and ACP primarily includes those encountered in California on plain-jointed PCCP and on ACP. Brief definitions of these are also included in Topic 612. The failure type terminology shown below is generally the same as that included in the Pavement Management System Manual of Rating Instructions which is available in each district through the HA22 Program Advisor.

611.5 PCCP Failure Types

(1) *Faulting.* Also called step-faulting, this is a phenomenon that is common on California's plain jointed PCCP. This occurs primarily at transverse joints and at "working transverse cracks", as a result of slab pumping action that occurs with the passage of each heavy truck axle when the structural section is saturated. Pumping may continue for several weeks after a rainstorm.

    A badly faulted pavement generally exhibits a history of shoulder distress adjacent to the edge of the traveled way, due primarily to the pumping of aggregate base fines from under the AC shoulder. Faulting, and the accompanying loss of full base support of the slab, generally precedes and is considered to be a major contributing factor to slab cracking and eventual breakup.

(2) *Slab Cracking.* Pavement cracks generally result from heavy wheel loading combined with lack of uniform base support. Cracking also results from weak subgrades, expansive soils and differential settlement. The degrees of cracking are described below.

(a) First-stage cracking. Non-intersecting transverse, longitudinal or diagonal cracks in a slab which divide the slab into two or three large pieces. This does not include corner breaks.

(b) Second-stage cracking. Transverse, longitudinal or diagonal cracks which develop in a slab within 0.6 m of planned or unplanned cracks or joints. Second stage cracking divides the slab into smaller pieces than first-stage cracking. The cracks are basically parallel and do not intersect.

(c) Third-stage cracking. Cracking of the slab into three or more pieces with interconnected cracks developing between cracks or joints.

(3) *Settlement.* Settlement is a local sag in the pavement that results from differential settlement or consolidation, or movement of the underlying earth mass. Sags most commonly occur above culverts due to the settlement or densification of backfill or at grade points between cut and fill sections. Sidehill slippage also contributes to differential settlement of the pavement and longitudinal cracking.

(4) *Blow-Ups*. Blow-ups are localized upward buckling and shattering of the slabs at transverse joints or cracks. Any area where the transverse joint openings become filled with incompressible solids or where insufficient joint has been provided is susceptible to blow-ups. Although blow-ups are not common in California, they occur in freeze-thaw areas where the pavement is sanded during the winter season and in areas subject to large temperature changes.

(5) *Joint or Crack Spalling.* Spalling is the breakdown or disintegration of slab edges at joints or cracks, usually resulting in the loss of sound concrete and progressive widening of the joint or crack. It occurs at joints or cracks when incompressible materials are confined in the opening. It also occurs where uniform slab support is lacking and there is vertical movement due to wheel load impact.

(6) *Surface Attrition.* Surface attrition or "surface abrasion" is abnormal surface wear of the concrete pavement, usually resulting from poor quality surface mortar or coarse aggregate. Surface attrition is especially accelerated by the action of tire chains and studded tires.

(7) *Surface Polish.* Surface polish is the loss of the original surface texture due to traffic action.

611.6 ACP Failure Types

(1) *Alligator Cracking.* Alligator cracks are a series of interconnected or interlaced cracks caused by fatigue failure of the AC surface under repeated traffic loading. The cracking initiates at the bottom of the AC pavement where strain, which occurs under wheel loads, is excessive and tensile stress is highest. These cracks are always load associated. Initially, the cracks appear as single longitudinal cracks or a series of parallel cracks in the wheel paths. Upon further loading, the cracks interconnect forming many-sided, sharp angled pieces which develop into a pattern resembling that of an alligator's hide. Alligator cracking is categorized into the three types in the PMS as outlined below.

- Type A. Initial single or parallel longitudinal fatigue cracks in the wheel paths.
- Type B. Interconnected fatigue cracks in the wheel paths.
- Type C. Other patterns of fatigue cracks due to a localized condition with minimal base or surface thickness.

Type C alligator cracking generally occurs outside the wheel paths. The cause of the condition is usually apparent, such as edge cracking due to widening of a pavement with minimal base or surface thickness. Other causes of Type C alligator cracking are mud-balls in the base, and pumping and deterioration at reflective cracks.

(2) Block Cracking. Block cracks are large interconnected polygons, usually with sharp corners or angles. These cracks are generally due to hardening and shrinkage of the asphalt and/or reflection cracking from CTB. The blocks may range in size from approximately 0.1 m^2 to 2.5 m^2. This type of distress is not load-associated, although load can increase the severity of individual cracks. Block cracking normally occurs over a large portion of the pavement area, but sometimes occurs only in nontraffic areas. The three severity levels of block cracking are given below.

(a) Light. Unsealed cracks that are not spalled (the sides of the crack are vertical) or cracks with only minor spalling (cracks with a mean width of 6 mm or less). Also, sealed cracks containing sealant that prevents moisture from entering, are block cracks of light severity.

(b) Medium. Blocks that contain sealed or unsealed cracks that are moderately spalled; unsealed cracks that are not spalled or have only minor spalling but have a mean width greater than 6 mm, or sealed cracks that are not spalled or have only minor spalling but have sealant in satisfactory condition.

(c) High. Blocks that are well-defined by cracks that are severely spalled.

(3) Transverse Cracking. Transverse cracks are approximately at right angles to the pavement centerline. They may be caused by shrinkage or differential thermal stress of the AC surface or hardening of the asphalt, or may be reflective cracks caused by breaks beneath the surface course, i.e. shrinkage cracks in CTB. The three severity levels of transverse cracking are outlined below.

(a) Light. Sealed or unsealed cracks that have little or no spalling. If sealed, they have a mean width of 6 mm or less. Sealed cracks are of any width, but their sealant material is in satisfactory condition to substantially prevent water from entering. No significant bump occurs when a vehicle crosses the crack.

(b) Medium. One of the following conditions exists:

- sealed or unsealed cracks of any width that are moderately spalled;
- sealed cracks are not spalled or have only minor spalling, but the sealant is in a condition so that water can enter freely;
- nonsealed cracks are not spalled or have only minor spalling, but mean crack width is greater than 6 mm;
- low severity random cracking exists near the crack or at the corners of intersecting cracks; or
- the crack causes a significant bump to a vehicle.

(c) High. One or more of the following are present:

- cracks are severely spalled;
- medium or high random cracking exists near the crack or at the corners of intersecting cracks; or
- the crack causes a severe bump to a vehicle.

(4) Longitudinal Cracking. Longitudinal cracks are approximately parallel to the pavement centerline. They may be caused by:

- poorly constructed paving lane joints,
- shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or
- a reflective crack caused by cracks beneath the surface course.

The severity levels for longitudinal cracks are the same as those given for transverse cracks in Index 611.6(3) above.

(5) Rutting. A rut is a surface depression in a wheel path which can cause pavement uplift. Rutting stems from a permanent deformation in any of the pavement layers or in the subgrade, usually resulting from consolidation or lateral movement of the layer due

to traffic loads. Rutting may be caused by plastic movement in the AC during hot weather, or inadequate compaction during construction. Significant rutting can lead to major structural failure of the pavement and hydroplaning potential. Light, medium and high severity rutting levels are described below.

(a) Light. Ruts whose mean depths range from 6 mm to 13 mm.

(b) Medium. Ruts which have average depths ranging from greater than 13 mm to 25 mm.

(c) High. Ruts with average depths that are greater than 25 mm.

(6) *Raveling.* Raveling is the wearing away of the pavement surface caused by the dislodging of aggregate particles and binder. This is generally due to insufficient asphalt binder in the mix or stripping of asphalt from particles of aggregate. The severity levels are outlined below.

(a) Fine. The fine aggregate and binder has worn away, and the surface texture is moderately rough and pitted.

(b) Coarse. The coarse aggregate and/or binder have worn away and the surface texture is severely rough and pitted.

(7) *Drip Track Ravel.* Drip track ravel is the progressive disintegration of the surface between wheel paths. This progressive disintegration of the surface between the wheel paths is caused by the dripping of oil and gas from vehicles. These petroleum products soften and weaken the bitumen causing the loss of the aggregate and binder. Ravel due to the leaching of asphalt binder by gas and oil, is primarily a condition which occurs at intersections where vehicles must come to a stop before proceeding.

(8) *Bleeding.* Bleeding, also known as flushing, is the exuding of bitumen onto the pavement surface which creates a shiny, glass-like, reflecting surface. Also, bleeding may be so extensive that streams of asphalt flow over the pavement's surface. Bleeding is generally caused by excessive amounts of asphalt cement in the mix and/or low air void contents. It occurs when asphalt fills the voids of the mix during hot weather and then expands out onto the surface of the pavement. Excess moisture in a pavement may cause stripping of asphalt which may also result in bleeding.

Since bleeding is not reversible during cold weather, asphalt will accumulate on the surface and cause a reduction in skid resistance.

611.7 General Pavement Rehabilitation Strategies

Pavement service life is affected by many factors. Each rehabilitation project should, therefore, be analyzed carefully to develop the most appropriate corrective action.

Factors which should be considered in determining appropriate corrective action include the following:

- Type, degree, extent and cause of deterioration,
- Rate of deterioration,
- Comparative lane deterioration,
- Base condition and underlying support,
- Retention or trapping of surface water in the structural section,
- Shoulder condition,
- Ride Score,
- Vertical Controls,
- Traffic loadings and volume,
- Pavement Deflection (ACP),
- Traffic handling alternatives,
- Conservation of materials and energy,
- Availability of new materials, and
- Cost.

During the service life of a pavement structural section, preventive maintenance work should be performed at the appropriate time to preserve the pavement structural section and thus postpone or minimize the magnitude of the pavement rehabilitation work that eventually will be required in the future. Capital preventive maintenance (CAPM) strategies are designed to extend the pavement service life for 5 years. Surface treatments (i.e.: seal coats, etc.) and "thin blanket" AC overlays are not CAPM strategies. See the Project Development Procedures Manual for CAPM project development procedures.

CAPM projects typically include such items as placement of additional surface material, grinding pavement surfaces, and/or other pavement structural section related work necessary to preserve the existing roadway. CAPM projects are not to include upgrading of geometric features and appurtenances for safety purposes and will not degrade the existing geometric design and safety features to below those which currently exist. All newly constructed project features are to be in conformance with current design and safety standards, policies and practices. CAPM projects which are consistent with the scope and intent of the CAPM program do not require an "Exceptions from Mandatory Design Standards Fact Sheet".

Reconstruction work, like new construction, is generally planned to provide either 10 or 20 years of future service life (as discussed in Index 603.2); whereas rehabilitation is a correction to extend the service life of an existing facility for at least 10 years. Reconstruction is designed to current geometric standards whereas rehabilitation generally conforms to existing geometric features with only minimal upgrading, see Index 307.3.

On many roadway segments, the outer (truck) lanes of multilane facilities have incurred structural damage from a high volume of heavy trucks while the median lanes have retained their structural adequacy. In these cases, outer lane reconstruction to restore structural adequacy and ride quality may be more cost effective than a structural overlay which must be carried across all adjacent lanes and shoulders. The presence of vertical grade controls, median barriers, drainage facilities, restrictive structure clearance, etc., can preclude the placement of a structural overlay and thus require lane reconstruction or reconstruction with a grade change.

Accordingly, rehabilitation strategies should represent the minimal improvement that will extend service life for at least 10 years.

Following is a description of various pavement rehabilitation strategies for both PCC and AC pavements and criteria for their use.

Rehabilitation strategies should generally conform to the following guidelines. Significant variations from these guidelines must be documented in the project approval document (PSSR, PR, etc.). The project approval document should also include the various alternatives studied and reasons why they were not recommended.

611.8 PCCP Rehabilitation Strategies

Caltrans has experimented with edge drains to rapidly remove infiltrated surface water and thereby to inhibit the pumping action that results in step faulting. Other corrective or preventive techniques that have been tried include cement-pozzolan grout subsealing to fill voids under slabs, replacement of cracked slabs, lane replacement, slab jacking (primarily at structure approaches) to raise settled slabs back to a smooth profile, diamond grinding to correct the profile of step-faulted surfaces, longitudinal grooving to inhibit hydroplaning and reduce wet weather skidding accidents, thin resin and special cement concrete overlays to restore surface profile and texture, cracking and seating of slabs in conjunction with asphalt concrete overlays, joint sealing, crack and joint spall repairs, thick unbonded concrete overlays, thin-bonded concrete overlays, and asphalt concrete overlays.

In the past, some of the above rehabilitation techniques have been used in a piecemeal manner to correct a symptom without getting to the root of the problem. For instance, step faulting at transverse joints has been corrected by grinding to restore a smooth surface profile without inhibiting the pumping action that created the faulting. As a result the pumping action continued and faulting, in some cases, built up to its pre-grinding level within 4 years. In other cases, asphalt overlays have been placed over deteriorated or rough concrete pavement without stabilizing rocking slabs or providing more positive structural section drainage. This has resulted in continued rocking of slabs, continued pumping action, the development of reflective cracking through the overlay, and additional step faulting. Thin overlays utilizing plastic resins and special cements are very high in cost and the potential benefits primarily are limited to improvements of profile, texture, and abrasion resistance.

Caltrans' current practice, based on experience and experimentation, is to use a single or a combination of several preventive or corrective techniques which will provide the best overall solution to extend the pavement life for 10 years or more. The choice of strategies depends primarily on the pavement condition and apparent rate of deterioration. The rate of deterioration is based on experience, field observation, and a review of progressive biennial PMS condition surveys.

(1) Slab Replacement and Grind. This strategy, both restorative and preventive, includes several techniques based on research, experience and engineering judgment. Portland cement concrete pavement that has deteriorated to an unacceptable ride, but is still structurally sound, benefits from this strategy. To warrant this strategy, the pavement must generally have a ride score greater than or equal to 45 and third stage cracking less than or equal to 10%.

Care should be taken to review the comparative percentage of slab cracking from PMS surveys to determine rate of deterioration. If the rate of deterioration (slab cracking) is increasing rapidly, consideration should be given to using the strategy discussed in Index 611.8(2).

The combined strategy used under these conditions is to: replace individual slabs which have multiple cracks and/or severe crack or joint spalling or depressions; grind to remove faulting and thereby to restore a smooth surface profile and repair spalled joints and cracks as necessary. Care should be taken in grinding not to leave vertical ridges in excess of 13 mm.

The repair of both interior and exterior PCCP slab corner breaks appears to be a critical factor in the performance of rehabilitated PCCP. The repair of small PCCP corner breaks should be made using full lane width partial slab replacements at least 2 m in length. Full depth sawing of the slab prior to removal and installation of a full depth 6 mm thick polyethylene foam expansion joint filler along the transverse joints prior to placing the new concrete are necessary to inhibit spalling along the transverse joints.

Transverse joint sealing should be specified in freeze-thaw areas, where sanding in the winter tends to fill the joints with incompressible materials. It is not, however, practical or necessary that this be a completely watertight joint. The primary purpose for joint sealing is to keep out the incompressible material.

When sealing transverse joints is specified on rehabilitation projects, the relatively low cost rubberized asphalt materials should generally be utilized. These materials are generally easier to maintain than the thermoplastic materials which have not performed well in limited usage on PCCP in California. Caltrans has experimented with the relatively high cost silicones for several years, but it is doubtful that the added cost is warranted on rehabilitation projects.

The slab replacement and grinding combination rehabilitation strategy is anticipated to provide a minimum of 10 years additional service without significant pavement maintenance.

(2) Crack and Seat Slabs, Install Edge Drains, and Place an AC Overlay with PRF Interlayer. This strategy is a combination of recycling, restoration, and preventive techniques. This strategy is used where concrete pavement has an unacceptable ride and is in an intermediate to advanced stage of structural deterioration. Generally, this means there is extensive third stage cracking (over 10%) of individual concrete slabs and it appears to be futile to try to "keep up" by utilizing individual slab replacement and grinding. Slab replacement is not appropriate under this strategy, unless there is complete disintegration of a slab or segment.

In this case, the combination strategy used is to crack and seat the PCCP slabs, install edge drains, and place a 105 mm DGAC overlay with a pavement reinforcing fabric (PRF) interlayer. This strategy should consist of first placing a 30 mm leveling course of DGAC, followed by a PRF, a 30 mm lift of DGAC and a final 45 mm lift of DGAC. If the criteria for OGAC has been satisfied, place a 30 mm DGAC leveling course followed by a PRF, a 45 mm lift of DGAC and a final lift of 30 mm of OGAC.

When an existing PCCP panel is shattered or badly spalled and the pieces are unstable under traffic, consideration should be given to removing the concrete panel by the "lift off" method, recompacting the base if necessary, and then placing full depth AC or accelerated set PCC. When accelerated set PCC is used, it is imperative that weakened plane joints be constructed on the paved centerline and transversely at panel quarter points to a depth of 3/4 the depth of the replacement slab. Formed joints shall be constructed by inserting 6 mm hardboard strips during placement of the PCC or by sawing. When these procedures are followed, it will not be necessary to crack the new slab prior to the seating process.

On four-lane divided freeways, both lanes in each direction are cracked and seated whereas on facilities with 3 or more lanes in each direction, if no significant distress or signs of deterioration exists in the median lane(s), they need not be cracked and seated before the overlay and fabric are placed.

The AC overlay includes a reinforcing fabric interlayer that extends at least 0.6 m outside the edge of PCCP into the shoulder area. The fabric interlayer retards infiltration of surface water and reflection cracking. It is assumed to be equivalent to 30 mm of AC in its effectiveness to prevent reflective cracking. This reduction of 30 mm in required thickness of AC can result in a significant savings, especially on multilane facilities. Where the slab deterioration is primarily limited to the outer lane or lanes on multilane facilities, an economic analysis should be made to compare the cost of lane replacement with the cost of overlaying all lanes and shoulders.

Care should be taken to feather the end of the AC overlay at the transition back to existing PCCP. This may be done either by the preferred method of feathering the AC on top of the PCCP or by milling a transition wedge taper into the PCCP.

In utilizing the cracking and seating procedure, which Caltrans considers to be one of the highest forms of recycling, the goal is to break the slabs into nominal 1.2 m x 1.8 m segments to serve as a stable base for the overlay. During the compaction of the first lift of the AC overlay, the slab segments are firmly seated onto the underlaying base by vibratory rollers. The cracking, seating, and rolling not only stabilizes the slab segments to minimize any differential vertical movement but it also reduces the magnitude of thermal movement and strains that are transmitted into the overlay and the PRF interlayer. This minimizes the reflective cracking tendency that has been observed on asphalt concrete overlays over PCCP.

The installation of edge drains, when combined with the PRF interlayer, minimizes the potential for entry and entrapment of water and pumping action of the PCCP segments under the AC overlay. The Pavement Consulting Services Branch in METS should be consulted on the advisability of installing retrofit or upgrading the existing edge drains on all crack, seat and AC overlay pavement rehabilitation projects.

The cracking, seating, installation of edge drains, and an AC overlay with a PRF interlayer combination strategy is anticipated to last a minimum of 10 years without requiring significant pavement maintenance.

(3) Grooving, Grinding, and Special Thin Surface Treatments. In addition to the 3 basic strategy combinations discussed above, other individual concrete pavement rehabilitation strategies are used or considered to solve specific problems. These include longitudinal grooving to minimize the potential for hydroplaning and skidding accidents, grinding only, as an interim measure (on selected projects) to improve the ride quality on very rough pavement pending major rehabilitation or reconstruction, and the application of very thin resin or special cement concrete overlays to improve the surface profile and

to restore the surface of pavement that has been abraded by tire chains and studs.

Grooving has proven to be effective in the reduction of hydroplaning and wet weather skidding accidents. The grooved surface is expected to remain effective for at least 10 years based on experience on California's busiest metropolitan freeways. The life of grooving is reduced where there is exposure to tire chains and studs. The longevity apparently varies inversely with the volume and mass of vehicles with chains and directly with the durability or abrasion resistance of the concrete.

Recent research on the grinding of PCC pavements indicates that the required surface texture, a coefficient of friction of not less than 0.30, will provide adequate skid resistance for a relatively long period of time. Therefore regrooving of a once grooved PCC pavement, subsequent to a grinding operation, should not be necessary unless there are extenuating circumstances.

The thin resin or special cement based concrete overlays utilizing methacrylates, magnesium phosphate cement, polymers, etc. are still considered to be experimental, and because of high cost their application, is limited to unique conditions or problem areas. The greatest potential for their use is on structure decks.

(4) *Partial or General Reconstruction*. When PCCP has deteriorated to the point that some reconstruction is required, alternatives might include outer (truck) lane replacement with minor work on other lanes, thick PCCP overlay with PCCP shoulders, recycling, and other strategies. The decision should be based primarily on economic considerations. On large projects, a life-cycle cost comparison must be done to substantiate project strategy decisions. The Pavement Consulting Services Branch in METS and OPPD should be contacted for assistance.

(5) *Structure Approach Slab (Pavement) Rehabilitation.* Structure approach pavement improvement is a key element of pavement rehabilitation, since this area is often the most difficult to maintain in a serviceable condition. Caltrans design practice is covered in Index 610.5.

(6) *PCCP Slab Replacement with Existing Edge Drains.* Care must be taken to prevent clogging of the existing edge drain system during rehabilitation projects. PCCP slab replacements can create problems with the existing edge drains. In this situation the length of slotted edge drain adjacent to, and 0.3 m beyond each end of, the PCCP must be removed along with the existing treated permeable material at the same time the existing slab(s) are removed to provide space for the side forms. After the PCCP has cured and the forms have been removed, Class 2 aggregate base, if needed, is placed in the trench previously occupied by the treated permeable material and compacted up to the bottom of the existing slotted drain stubs. Unslotted PVC pipe is attached using band couplers to reconnect the edge drain system and additional Class 2 aggregate base is placed and compacted to within 75 mm of the top of the new PCCP slab. The remaining 75 mm is backfilled with dense graded asphalt concrete. This procedure was developed because of the delay in replacing the filter fabric and treated permeable material during the short construction window available.

(7) *PCCP CAPM Strategies.* Capital preventive maintenance strategies (strategies that extend pavement service life for five years) for PCC pavements may involve such types of work as: pavement grinding to correct ride and/or faulting; slab replacement; spall repair; and seal random cracks; structure approach slab replacement; etc.

(8) *Positive Drainage Emphasis.* Although all aspects of the rehabilitation strategies are important, the most critical factor addressed by the Caltrans PCCP rehabilitation practice is providing positive drainage by installation of edge drains, to arrest the pumping action that has been so damaging to truck lanes and shoulders. The importance of improving drainage cannot be overemphasized.

611.9 ACP Rehabilitation Strategies

There are several kinds of problems or failures that AC pavements can experience. These failures can occur individually or in combinations, which is somewhat responsible for the broad range treatments that are available to repair AC. The level of treatment depends on the type(s) and severity of the failure types described in Index 611.6. Some treatments correct only one problem type, while others (like a structural overlay) correct several kinds of problems.

Caltrans created several operations programs to effectively address this broad range of problems in the life-cycle of AC pavements:

- Routine maintenance;
- Major maintenance;
- Preventive maintenance;
- Rehabilitation;
- Reconstruction;
- New facilities;

all utilize contracts, plans and specifications to some degree to correct the problems.

Some of the treatments that are used in these programs are:

- Crack filling;
- Patching;
- Digout and patch;
- Strip patch;
- Heater scarify;
- Grinding;
- Milling;
- Seal coats;
- Recycle;
- Overlay; and,
- Remove and replace (reconstruction).

The cost effective repair of pavement (pavement management) is more of an art than science. A great deal of research and experimentation has been done, and is continuing, but there are no accepted formula or textbook solutions for many of the problem types. The most predictable results are obtained from "designed" overlays and reconstruction.

The Maintenance Program is making more extensive use of pavement repair contracts. The Maintenance Program Manager is the decision maker in all matters relating to these contracts. Approval of a Phase 1 Expenditure Authorization typically constitutes project concept approval. See the Project Development Procedures Manual for details on project initiation and approval procedures. The District Division of Maintenance will determine the project limits, materials to be used, application rates and special provision requirements. Staff from the Maintenance Program in the Corporate Headquarters and METS are available for consultation in the event of questions or problems. It is also important to consult with the District Division of Operations to determine if there is a need to include any special traffic handling requirements in the special provisions.

(1) Bituminous Seals. Bituminous seals are used primarily for both maintenance and rehabilitation of ACP.

(a) Fog Seals. A fog seal consists of an application of asphaltic emulsion with additional water. It is primarily used to prevent moisture and air from entering asphalt concrete pavement and to recondition a dry or weathered asphalt surface. Care should be taken to obtain assurance that the fog seal will penetrate into the pavement and to avoid application of the fog seal when wet weather is imminent. A fog seal should not typically be used on a new construction project.

(b) Rejuvenator Seal. A rejuvenator seal consists of an application of a rejuvenating agent to an existing AC pavement. The pavement surface must be porous, allowing the rejuvenating agent to penetrate the existing surface. Traffic action will rework the upper 6 mm to 10 mm of the pavement surface; rejuvenating the old oxidized asphalt and resealing the fine cracks in the pavement. Application of rejuvenator seals should be avoided when wet weather is imminent.

(c) Sand Seal. A sand seal consist of an application of emulsified asphalt covered with fine aggregate. It is used to seal against air and water intrusion and improve the skid resistance of the pavement surface.

(d) Chip Seals. A chip seal generally consists of an application of an asphalt binder with a cover of screenings. It is primarily used on asphalt concrete pavements to mitigate surface raveling, to provide a skid resistant wearing surface, to prevent moisture and air from entering the pavement, and to recondition a dry or weathered surface. It may also be used on structure decks to provide a skid resistant surface in areas where frost is common, on detours as a temporary surface, or as a temporary surface during stage construction where light traffic is predicted.

(e) Slurry Seals. A slurry seal consists of a mixture of asphaltic emulsion, fine aggregate, and water. It is used to fill shrinkage cracks, to prevent air and moisture from penetrating the pavement, and to recondition dry or weathered asphalt concrete pavements. It generally provides a good skid resistant texture. A slurry seal is sometimes used as a surface treatment before applying an asphalt concrete overlay.

(2) AC Overlay. Development of recommendations for AC overlays and other rehabilitation strategies are the responsibility of the Pavement Consulting Services Branch in METS. This involves using deflection measurements in conjunction with pavement condition surveys and pavement cores to determine AC thickness and condition. The procedure will be described in the Caltrans "Pavement Rehabilitation Manual", see Index 601.1.

The overlay requirements are determined by considering the AC thickness needed for structural adequacy and for minimizing reflection cracking. Both factors contribute greatly to the final performance of the overlay.

Determining an adequate overlay to minimize reflection cracking requires a great deal of engineering judgment. The type, size and amount of surface cracking, the extent of localized failures, the age and condition of the existing structural section, the thickness and performance of previous overlays, the environmental factors and the anticipated traffic loadings all play roles in the decision process.

Several other factors should be considered when determining overlay requirements. These factors include:

- The presence of vertical grade controls (curbs, gutters, structures, guard rails, etc.) which may limit the thickness to less than that needed for a 10-year service life extension,
- The possibility of reducing the overlay thickness by digging out and repairing localized failures and/or removing and replacing the upper portion of the existing AC prior to the overlay,
- The feasibility of using a pavement reinforcing fabric interlayer or SAMI (Stress-Absorbing Membrane Interlayer) or rubberized AC overlay to reduce the overlay thickness where overlay thickness is governed by reflection cracking, and
- An economic comparison of the overlay and other rehabilitation strategies, i.e., recycling.

After all of the above factors have been considered, a final strategy is developed to economically extend the service life of the roadway for the specified design period.

(3) Recycling of Asphalt Concrete. Recycling, where feasible, can be used as an acceptable rehabilitation strategy (see Deputy Directive Number DD-17). Equipment has been developed to mill existing AC pavements rapidly and effectively to permit recycling old pavement materials.

Recycled AC has several uses:

- AC surface course when blended with virgin aggregate and rejuvenating agent or paving asphalt;

- AC base course covered by virgin AC surface course;
- Class 3 aggregate base; and,
- shoulder backing material.

Hot recycling involves removal of all or part of the existing AC pavement, hauling this reclaimed asphalt pavement (RAP) to a storage location, combining it at high temperature with virgin aggregate and a rejuvenating agent or paving asphalt, and placing this recycled mixture with conventional paving equipment. For purposes of estimating, a recycled mix containing 50 percent RAP should be assumed. Hot Recycled AC (HRAC) mix should be designed using not more than 50% RAP.

Cold recycling involves milling or pulverizing the existing AC and mixing it with a recycling agent or asphalt emulsion, with or without the addition of virgin aggregate, and then placing this cold mixture with conventional paving equipment. Cold Recycled AC (CRAC) pavement is "capped" with a hot mixed surface course of at least 45 mm DGAC.

AC recycling will usually prove cost-effective in the following situations:

- where quantities involved are large (combining nearby projects should be considered).
- where reflection cracking control dictates overlay thickness.
- where vertical controls (i.e., structure clearance, guardrail heights, etc.) restrict overlay thickness.
- where acceptable quality aggregate is not readily available.
- where an overlay would be required on undistressed lanes of multilane facilities. (Recycling allows the rehabilitation of only one lane or parts of a lane. On the other hand, a conventional overlay strategy necessarily involves overlaying all adjacent lanes, even those that may not be in need of rehabilitation.)

The feasibility of AC recycling must be addressed in all project approval documents (PSSR, PR, etc.). The Deflection Study Report conducted by the Pavement Consulting Services Branch in METS will usually make an initial evaluation of recycling feasibility and recommend specific recycling alternative(s) that will satisfy the structural needs of the roadway. The Geotechnical Design Report or Materials Report must also address recycling and provide information as to the recyclability of the pavement in question.

The PE is responsible for a more detailed evaluation of the recommended alternatives with regard to project-specific conditions. The recycling option must be compared to other rehabilitation alternatives on the basis of cost, feasibility, energy consumption, raw material savings, and specific job conditions. Cost comparisons with alternative strategies must be made using current unit cost data.

(4) Preliminary Work Prior to Rehabilitation.

(a) Seal Cracks. Cracks are generally attributable to the lack of base support, volume change in the asphalt mix because of temperature changes and age hardening of the asphaltic concrete mix. Cracks should be repaired to prevent the entrance of moisture.

Cracks may be refilled with emulsion, liquid asphalt or, in the case of wider cracks, by special asphalt combinations or heavier bodied asphalt material. Small cracks such as alligator cracks may often be repaired by tacking a blocked out area and applying chips or other similar material. A thin skin patch of hot plant mix may also be used for crack sealing.

Slippage cracks are caused by the lack of a good bond between the pavement surface and the underlying layer. The only way to permanently repair a slippage crack is to remove the delaminated portion of the AC, clean and tack the surface and then to replace it with plant mixed AC.

(b) Repair Localized Failures. Generally, the existing AC surfacing at severely failed localized areas (loose or spalled pavement) is removed and replaced with new AC prior to placing an AC overlay. If there is base failure (rutting ≥ 13 mm), the base, as well as the AC, may be removed and replaced with new AC prior to placing an AC overlay. In most cases, the depth of the repair should not exceed 150 mm.

When patching is performed, the loose material is removed, and the area is primed with liquid asphalt or an emulsified asphalt. Then, the area is patched with premixed material or a special mix designed for placing in periods of cold or inclement weather.

(c) Repair Work Prior to Cold Recycling AC. Extensive maintenance work in advance of cold recycling an existing AC pavement should be avoided. If the selected pavement rehabilitation strategy is CRAC, the recommendations provided by the METS Pavement Consulting Services Branch in the deflection study report should be followed.

(5) ACP CAPM Strategies. Capital preventive maintenance strategies (strategies that extend pavement service life for five years) for AC pavements may involve such types of work as : digout repairs of locally failed areas, “thick blanket” (single construction pass) 45 mm to 60 mm DGAC overlays; “thick blanket” (single construction pass) 30 mm to 60 mm rubberized AC overlays; placing shoulder backing material, etc. Surface treatments (seal coasts) and “thin blanket” (24 mm) AC overlays are not capital preventive maintenance strategies.

611.10 Traffic Handling and Safety

One of the first considerations in developing a pavement rehabilitation project is for the safety and handling of traffic during rehabilitation work, as well as, the safety for state and contractor worker's. Adequate attention must be given to traffic handling and safety to obtain the required quality of work with minimal increases in project costs. Some traffic handling alternatives are given below.

(1) Complete Roadbed Closure. Maximum productivity, quality, and economy result if the roadway can be closed completely during the entire rehabilitation period. This requires the rerouting of traffic over other routes.

(2) Continuous Lane Closures. Since the outside (truck) lane(s) generally suffer(s) the greatest pavement damage, lane replacement can sometimes be accomplished by complete closure of the lane(s) during the reconstruction stage. Here, temporary restriping and narrower lanes or added AC median paving should be considered. The use of temporary concrete barrier rail may be justified in special circumstances. Where practicable, a minimum of 2 m of clearance should be provided between traffic and paving operations.

(3) Weekend Closures. Weekend closures should be considered in high volume traffic areas, where lane closures may cause severe congestion and result in accidents and delays to the motorist. These closures also impact local businesses. When replacing PCCP slabs, fast setting concrete must be specified to permit reopening to Monday morning traffic.

(4) Nighttime Closures. This is the least desirable alternative, but sometimes it is the only feasible solution. When replacing PCCP slabs, fast setting concrete is generally required and the cost of the work is relatively much higher.

Additional traffic handling alternatives that may be appropriate include the use of construction staging, temporary ramps, detours and signing. The District Division of Operations should be consulted for guidance on all traffic handling and safety issues.

611.11 Conservation of Materials and Energy

Paving materials such as cement, asphalt, and rock products are becoming more scarce and expensive, and the production processes for these materials consume considerable energy. Increasing evidence of the limitation of nonrenewable resources and increasing worldwide consumption of most of these resources requires optimal utilization and careful consideration of alternates such as the substitution of more plentiful or renewable resources and the recycling of existing materials.

(1) *PCC Pavement.* The crushing and reuse of old PCC pavement as aggregate in new PCC or AC pavement does not now appear to be a cost-effective alternate, primarily because of the availability of good mineral aggregate in most areas of California. However, if it appears that this may be a feasible option, because of unique project conditions or the potential lack of readily available materials, it may be included in a cost comparison of alternate solutions.

(2) *AC Pavement.* Recycling of existing AC must be considered, in all cases, as an alternative to placing 100% new asphalt concrete. This is discussed in more detail in Index 611.9(3) and in Deputy Directive Number DD-17.

(3) *Use of Asphalt Concrete Grindings, Chunks and Pieces.* Section 5650 of the Fish and Game Code states that it is unlawful to deposit asphalt, other petroleum products, or any material deleterious to fish, plant life, or bird life where they can pass into the waters of the State. In addition, Section 1601 of the Fish and Game Code requires notification to the California Department of Fish and Game (DFG) prior to construction of a project that will result in the disposal or deposition of debris, waste or other material containing crumbled, flaked, or ground pavement where it can pass into any river, stream, or lake designated by the DFG. When constructing transportation facilities, Caltrans frequently uses asphalt in mixed or combined materials such as asphalt concrete (AC) pavement. Caltrans also uses recycled AC grindings and chunks. There is a potential for these materials to reach the waters of the State through erosion or inappropriate placement during construction.

The first step is to determine whether there are waters of the State in proximity to the project that could be affected by the reuse of AC. Waters of the State include: (1) perennial rivers, streams or lakes that flow or contain water continuously for all or most of the year; or (2) intermittent lakes that contain water from time to time or intermittent rivers or streams that flow from time to time, stopping and starting at intervals, and may disappear and reappear. Ephemeral streams, which are generally exempt under provisions developed by Caltrans and DFG, are those that flow only in direct response to rainfall.

The reuse of AC pavement grindings will normally be consistent with the Fish and Game Code and not require a 1601 Agreement when these materials are placed where they cannot enter the waters of the State. However, there are no set rules as to distances and circumstances applicable to the placement of asphaltic materials. Placement decisions must be made on case-by-case basis, so that such materials will be placed far enough away from the waters of the State to prevent weather (erosion) or maintenance operations from dislodging the material into State waters. Site-specific factors (i.e., steep slopes) should be given special care. Generally, when AC pavement grindings are being considered for placement where there is a potential for problems, DFG should be notified to assist in determining whether a 1601 Agreement is appropriate and what mitigation strategies are available to prevent the materials from entering the waters of the State. When in doubt, it is recommended that the DFG be notified.

If there is the potential for reused AC materials to reach waters of the State through erosion or other means during construction, such work would normally require a 1601 Agreement. Depending on the circumstances, the following measures should be taken:

- The reuse of AC pavement grindings as fill material and shoulder backing must conform to the Caltrans Standard Specifications, applicable manuals of instruction, contract provisions and the MOU described below.
- AC chunks and pieces in embankments must be placed above the water table and covered by at least one foot of material.

A Memorandum of Understanding (MOU) dated January 12, 1993, outlines the interim agreement between the DFG and Caltrans regarding the use of asphaltic materials. This MOU provides a working agreement to facilitate Caltrans' continued use of asphaltic materials and avoid potential conflicts with the Fish and Game Code by describing conditions where use of asphalt road construction material by Caltrans would not conflict with the Fish and Game Code.

Specific Understandings contained in the MOU are:

· Asphalt Use in Embankments

  Caltrans may use AC chunks and pieces in embankments when these materials are placed where they will not enter the waters of the State.

· Use of AC Pavement Grindings as Shoulder Backing

  Caltrans may use AC pavement grindings as shoulder backing when these materials are placed where they will not enter the waters of the State.

· Streambed Alteration Agreements

  Caltrans will notify the DFG pursuant to Section 1601 of the Fish and Game Code when a project involving the use of asphaltic materials or crumbled, flaked, or ground pavement will alter or result in the deposition of pavement material into a river, stream, or lake designated by the DFG. When the proposed activity incorporates the agreements reached under Section 1601 of the Fish and Game Code, and is consistent with Section 5650 of the Fish and Game Code and this MOU, the DFG will agree to the use of these materials.

There may be circumstances where agreement between the DFG and Caltrans cannot be reached. Should the two agencies reach an impasse, the agencies enter into a binding arbitration process outlined in Section 1601 of the Fish and Game Code. However, keep in mind that this arbitration process does not exempt Caltrans from complying with the provisions of the Fish and Game Code. Also it should be noted that this process is time consuming, requiring as much as 72 days or more to complete. Negotiations over the placement of AC grindings, chunks and pieces are to take place at the District level as part of the 1601 Agreement process.

Topic 612 - Pavement Structural Section Definitions

The following list of definitions includes a number of terms that are not commonly used in California. Some are terms which are included in the "AASHTO Guide for the Design of Pavement Structures" and may be used by FHWA, local agencies, consultants, etc. when discussing pavement structural sections. Some will be common terms in pavement design and research publications that the PE may want to read.

Alligator Cracking. Interconnected or interlaced load associated (fatigue) cracks in asphalt concrete pavement forming a series of small polygons that resemble the typical pattern of an alligator's skin.

Analysis Period. The period of time for which the economic analysis is to be made; ordinarily will include at least one rehabilitation activity. This has been termed "economic life-cycle period" in the Caltrans procedures, for the purpose of selecting the pavement type based on long-term costs.

Asphalt Treated Permeable Base (ATPB). A highly permeable open-graded mixture of crushed coarse aggregate and asphalt binder placed as the base layer to assure adequate drainage of the structural section, as well as structural support.

Base. A layer of selected, processed, and/or treated aggregate material of planned thickness and quality placed immediately below the pavement and above the subbase or basement soil to support the pavement.

Basement Material. The material in excavation or embankments underlying the lowest layer of subbase, base, pavement surfacing or other specified layer which is to be placed.

Basement Soil. See Basement Material.

Block Cracking. Interconnected cracks on flexible pavement, that are not load associated, which form a series of large polygons usually with sharp corners or angles.

Blow-up. Localized upward buckling or a shattering of a rigid pavement slab at or near a transverse joint or crack.

Borrow. Natural soil obtained from sources outside the roadway prism to make up a deficiency in excavation quantities.

Cement Treated Permeable Base (CTPB). A highly permeable open-graded mixture of coarse aggregate, portland cement, and water placed as the base layer to provide adequate drainage of the structural section, as well as structural support.

Chip Seal. A high viscosity asphaltic emulsion surface coat which incorporates rolled in rock screenings (chips) over an asphalt concrete pavement, as preventive maintenance, to extend the service life.

Cold Recycling. The rehabilitation of asphalt concrete pavement without the application of heat by milling and mixing with new binder and/or rejuvenating agents in place.

Composite Pavement. A pavement structure or structural section composed of an asphalt concrete wearing surface and portland cement concrete slab; an asphalt concrete overlay on a PCC slab is also referred to as a composite pavement.

Construction Joint. A joint made necessary by a prolonged interruption in the placing of concrete.

Contraction Joint. See Weakened Plane Joint.

Dense Graded Asphalt Concrete (DGAC). A uniformly graded asphalt concrete mixture (aggregate and paving asphalt) containing a small percentage of voids, used primarily as a surface layer to provide the structural strength needed to distribute loads to underlying layers of the structural section.

Design Period. The period of time that an initially constructed or rehabilitated pavement structural section is designed to perform before reaching its terminal serviceability or a condition that requires major rehabilitation or reconstruction; this is also referred to as the performance period. Because of the many independent variables involved, the service life before major maintenance or rehabilitation is required may actually be considerably longer or shorter.

Dowel. A load transfer device in a rigid slab usually consisting of a plain round steel bar. These are not currently used in Caltrans practice. (See Load Transfer Device).

Drainage Coefficients. AASHTO Design Guide factors used to modify layer coefficients in flexible pavement or stresses in rigid pavements as a function of how well the pavement structure can handle the adverse effect of water infiltration. These are not used in Caltrans' pavement structural section design procedures. The positive drainage features required and used by Caltrans obviates their need.

Drip Track Ravel. Progressive disintegration of the surface between wheel paths on asphalt concrete pavement, caused by oil and fuel dripping from vehicles. This is most prevalent adjacent to intersections where vehicles slow and stop.

Edge Drain System. A drainage system, consisting of a slotted plastic collector pipe encapsulated in treated permeable material and a filter fabric barrier, with unslotted plastic pipe vents, outlets, and cleanouts, designed to drain the structural section of both rigid and flexible pavements.

Embankment. A prism of earth that is constructed from excavated or borrowed natural soil and/or rock, extending from original ground to the grading plane, and designed to provide a stable support for the pavement structural section.

Equivalent Single Axle Loads (ESAL's). Summation of equivalent 80 kN single axle loads used to convert mixed traffic to design traffic for the design period.

Expansion Joint. A joint located to provide for expansion of a rigid slab, without damage to itself, adjacent slabs or structures.

Faulting ("Step-off"). Differential vertical displacement, primarily at transverse joints, of abutting rigid slabs which creates a "step-off" in the pavement surface profile.

Flexible Pavement. A traffic load carrying system that is made up of one or more layers that are designed to transmit and distribute that loading to the underlying roadbed material. The highest quality layer is the surface course, (generally asphalt concrete) which is usually underlaid by a lesser quality base, and in turn a subbase. It is called flexible because it can tolerate deflection bending under heavy loads.

Fog Seal. A combination of mixing-type asphaltic emulsion and water which is applied to the surface of asphalt concrete pavement to seal the surface, primarily used for pavement maintenance.

Grading Plane. The surface of the basement material upon which the lowest layer of subbase, base, pavement surfacing, or other specified layer, is placed.

Hot Recycling. The use of reclaimed asphalt concrete pavement which is combined with virgin aggregates, asphalt, and sometimes rejuvenating agents at a central hot-mix plant and placed in the structural section in lieu of all new materials.

Joint Seals. Pourable, or extrudable, or premolded materials that are placed primarily in transverse and longitudinal joints in or along the edge of concrete pavement to deter the entry of water and incompressible materials (such as sand that is broadcast in freeze-thaw areas to improve skid resistance).

Layer Coefficient (a_1, a_2, a_3). An AASHTO Design Guide term denoting the empirical relationship between structural number (SN) and layer thickness which expresses the relative ability of a material to function as a structural component of the pavement. This is not used in Caltrans' pavement structural section design procedures.

Lean Concrete Base. Mixture of aggregate, portland cement, water, and optional admixtures, primarily used as a base for portland cement concrete pavement.

Leveling Course. The layer, generally of AC or other treated or processed material, that is placed over the rough or undulating surface of an existing pavement, structure deck, or other surface to improve the surface profile or ride quality before placement of subsequent layers.

Lime Treatment. The mixing of lime with native or embankment materials to increase the strength (R-value) of the material which supports the pavement structural section.

Load Transfer Device. A mechanical means designed to carry loads across a joint in a rigid slab. These are not currently used in Caltrans practice for transverse joints; the aggregate interlock of the PCCP slabs and base support is considered to be the load transfer mechanism. For longitudinal joints see Tie Bars.

Longitudinal Cracking. Cracks or breaks in flexible or rigid pavement which are approximately parallel to the pavement center line.

Longitudinal Joint. A joint normally placed between traffic lanes in rigid pavements to control longitudinal cracking and the joint between the traveled way and the shoulder.

Low-Volume Road. A roadway generally subjected to low levels of traffic; in the AASHTO Design Guide, structural design is based on a range of 80 kN ESAL's from 50 000 to 1 000 000 for flexible and rigid pavements, and from 10 000 to 100 000 for aggregate-surfaced roads.

Maintenance. The preservation of the entire roadway, including pavement surface and structural section, shoulders, roadsides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

Modulus of Subgrade Reaction (k). Westergaard's modulus of subgrade reaction for use, under AASHTO Design Guide methods, in rigid pavement design (the load in Pascals (Pa) on a loaded area of the roadbed soil or subbase divided by the deflection in millimeters of the roadbed soil or subbase, Pa/mm). This is not used in Caltrans' pavement structural section design procedures.

Open Graded Asphalt Concrete (OGAC). An open graded mixture of aggregate and a relatively high asphalt content which provides good skid resistance and a high permeability. OGAC is designed to accommodate rapid surface drainage and minimize the potential of hydroplaning while at the same time providing an effective seal of the underlying asphalt concrete pavement.

Overlay. An overlay is a layer, usually asphalt concrete, placed on existing asphalt or portland cement concrete pavement to restore ride quality, to increase structural strength (load carrying capacity), and to extend the service life.

Panel Length. The distance between adjacent transverse joints in a traffic lane.

Pavement. The surface layer of the structural section that carries traffic. Except for special or experimental surface layers, the pavement is either portland cement concrete or asphalt concrete. The asphalt concrete layer may include up to a 30 mm layer of OGAC.

Pavement Management System (PMS). A management system, which was developed by Caltrans, to assess the condition of pavement, biennially, on the entire California State Highway System, and to prioritize and program the rehabilitation of pavement consistent with available funding.

Pavement Performance. The trend of serviceability with load applications.

Pavement Rehabilitation. Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy, for a minimum period of 10 years. This might include the partial or complete removal and replacement of portions of the pavement structural section.

Pavement Reinforcing Fabric (PRF). A nonwoven, bonded-fiber, engineering grade synthetic fabric that is, as used by Caltrans, placed as an interlayer in asphalt concrete overlays primarily to minimize surface water infiltration and retard reflection cracking through the overlay, from cracks or joints in the existing pavement.

Pavement Structure. See Structural Section

Pavement Surfacing. See Surface Course

Prepared Roadbed. In-place soils compacted or stabilized according to provisions of applicable specifications.

Present Serviceability Index (PSI, p). Term from the AASHTO Design Guide, a number derived by formula for estimating the serviceability rating from measurements of certain physical features of the pavement. Not used directly by Caltrans for pavement evaluation but conversion is made in PMS, for comparison.

Preventive Maintenance. Typically, capital outlay work performed to preserve the existing pavement structural section utilizing strategies that extend pavement service life for 5 years (i.e.: for AC pavements, “thick blanket” overlays; for PCC pavements, grinding, slab replacement, etc.).

Prime Coat. The application of a low viscosity liquid bituminous material to an absorbent surface (preparatory to placing subsequent structural section layers or PRF) for the purpose of hardening or toughening the surface and promoting adhesion between it and the superimposed constructed layer or PRF interlayer.

Pumping. The ejection of foundation material, either wet or dry, through joints or cracks, or along edges of rigid slabs resulting from vertical movements of the slab under traffic. This phenomena is especially pronounced with saturated structural sections.

Raveling. Progressive disintegration of the surface downward on asphalt concrete pavement by the dislodgement of aggregate particles and binder. Stripping usually precedes raveling.

Resilient Modulus. An AASHTO Design Guide term, a measure of the modulus of elasticity of roadbed soil or other pavement material. This is not used in Caltrans’ pavement structural section design procedures.

Resurfacing. A supplemental surface layer or replacement layer placed on an existing pavement to restore its riding qualities or to increase its structural (load carrying) strength.

Rigid Pavement. Primarily portland cement concrete pavement which distributes the superimposed axle loads over a relatively wide area of underlying structural section layers and soil because of its rigidity and high modulus of elasticity.

Roadbed. The roadbed is that area between the intersection of the upper surface of the roadway and the side slopes or curb lines. The roadbed rises in elevation as each increment or layer of subbase, base, surfacing or pavement is placed. Where the medians are so wide as to include areas of undisturbed land, a divided highway is considered as including two separate roadbeds.

Roadbed Material. Also referred to as basement soil or basement material, the material below the grading plane in cuts and embankments, extending to such depths as affect the support of the pavement structure or structural section.

Rubberized Asphalt. A mixture of paving asphalt combined with specified percentages of granulated reclaimed rubber for use as the binder in asphalt concrete and in stress absorbing membrane interlayers within or under asphalt concrete overlays. Primary applications where benefits appear to be significant are for providing more resilient and more durable wearing surface for overlays, to retard reflection cracking and overlays on pavement exposed to wear by tire chains. Rubberized asphalt joint sealant is used to keep incompressible materials out of joints in concrete pavement and retard surface water infiltration in concrete pavement.

Rutting. Longitudinal depressions that develop in the wheel paths of flexible pavement under traffic. This permanent and sometimes progressive deformation is most often caused by unstable asphalt concrete pavement or inadequate strength of the underlying foundation. Rutting may also occur in asphalt and concrete pavements due to chain or studded tire abrasion or raveling.

R-value. Resistance value of treated or untreated soil or aggregate as determined by the stabilometer test (California Test 301). This is a measure of the supporting strength of the basement soil and subsequent layers used in the design of pavement structural sections.

Seal Coat. A bituminous coating, with or without aggregate, applied to the surface of a pavement for the purpose of waterproofing, preserving, or rejuvenating a cracked or raveling bituminous surface, or to provide increased skid resistance or resistance to abrasion by traffic.

Selected Material. A suitable native material obtained from a specified source such as a particular roadway cut or borrow area, or a suitable material having specified characteristics to be used for a specific purpose.

Serviceability. The ability at time of observation of a pavement to serve traffic (autos and trucks) which use the facility.

Settlement. Localized vertical displacement of the pavement structural section due to slippage or consolidation of the underlying foundation, often resulting in pavement cracking, poor ride quality and deterioration.

Shoulder Backing. A material that is placed adjacent to the outside edge of the shoulder surfacing to protect the edge from spalling, and to provide edge support.

Single Axle Load. The total load transmitted by all wheels whose centers may be included between two parallel transverse vertical planes 1.016 m (40 inches) apart, extending across the full width of the vehicle.

Slab Cracking. Rigid pavement cracks generally resulting from a combination of heavy wheel loading, pumping action, and the resultant loss of uniform base support.

Slurry Seal. A mixture of mixing-type asphaltic emulsion, fine mineral aggregate and water proportioned, mixed and spread primarily on asphalt concrete pavement for maintenance purposes.

Spalling. Cracking, breaking, or chipping of a rigid pavement along joints, edges, or cracks in which small portions of the slab are dislodged. Spalling is caused primarily by incompressibles confined in the opening or nonuniform slab support in conjunction with vertical movement due to wheel load impact.

Stress Absorbing Membrane Interlayer (SAMI). An interlayer placed within or at the bottom of an asphalt concrete overlay or layer to retard reflective cracking. It does not add to the structural strength. Examples of SAMI's include: a rubberized chip seal interlayer or pavement reinforcing fabric. It is given an equivalency of 30 mm AC in an AC overlay designed to prevent reflection cracking.

Stripping. The loss of the adhesive bond between asphalt cement and aggregate, most often caused by the presence of water in asphalt concrete, which may result in raveling, loss of stability and load carrying capacity of the asphalt concrete pavement or treated base.

Structural Number (SN). An index number used in the AASHTO Design Guide methods, which is derived from an analysis of traffic, roadbed soil conditions, and environment which may be converted to thickness of flexible pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure. This is not used in Caltrans' pavement structural section design procedures.

Structural Section. The planned, engineering design of layers of specified materials (normally consisting of subbase, base, and pavement surface) placed over the basement soil to support the traffic loads anticipated to be accumulated and applied during the design period. The structural section is also commonly called the pavement structural section.

Structural Section Drainage System. A drainage system used for both asphalt and portland cement concrete pavements consisting of a treated permeable base layer and a collector system which includes a slotted plastic pipe encapsulated in treated permeable material and a filter fabric barrier with unslotted plastic pipe as vents, outlets and cleanouts to rapidly drain the pavement structural section.

Subbase. A layer of aggregate of designed thickness and specified quality placed on the basement soils as the foundation for a base.

Subgrade. That portion of the roadbed on which pavement surfacing, base, subbase, or a layer of any other material is placed.

Surface Attrition ("Abrasion"). Abnormal surface abrasion wear of pavement, resulting from either a poor quality surface or exposure to abnormal abrasive action (such as tire chains and sanding materials) or both.

Surface Course. The top layer of AC pavement. It is also sometimes called the "wearing course".

Surface Polish. The loss of the original pavement surface texture due to traffic.

Surface Recycling. In-place heating of the surface of asphalt concrete pavement followed by scarification, remixing, and compaction, generally to a depth of about 20 mm. This is considered to be a maintenance procedure.

Tack Coat (Paint Binder). The application of bituminous material to an existing surface to provide bond between the superimposed construction and the existing surface.

Tandem Axle Load. The total load transmitted to the road by two consecutive axles whose centers may be included between parallel vertical planes spaced more than 1.016 m (40 inches) and not more than 2.438 m (96 inches) apart, extending across the full width of the vehicle.

Thin Bonded Concrete Overlays (BCO). An overlay, of existing concrete pavement which is designed to improve ride and structural condition. Generally BCOs are about 75 mm thick, consisting of conventional low slump portland cement concrete or concrete containing polymers, or latex, or magnesium phosphate, or other additives designed to accommodate placement, improve bonding, and improve durability. Bonding is accomplished by epoxy or other types of adhesives. BCOs are still considered to be experimental. Research by METS is continuing.

Tie Bars. Load Transfer devices, usually deformed reinforcing bars placed at intervals, that hold rigid pavement slabs in adjoining lanes and exterior lane-to-shoulder joints together and prevent differential vertical movement.

Transverse Cracking. Cracks in asphalt concrete pavement approximately at right angles to the center line, most often created by thermal forces exceeding the tensile strength of the asphalt concrete. (Transverse cracks also occur in PCCP but are more often caused by live load stresses combined with uneven base support.)

Weakened Plane Joint. Commonly called a contraction joint, a joint normally placed at recurrent intervals in a rigid slab to control transverse cracking.

Weathering. Gradual degradation of asphalt concrete due to oxidation and hardening, especially of the surface layer resulting in transverse cracking and surface raveling.

Wearing Course. See Surface Course.